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(54) Title: DETECTING DNA DAMAGE, MEASURING DNA REPAIR RATES, AND MONITORING DNA REPAIR ENZYME ACTIVITY			
(57) Abstract <p>The present invention includes an improved method to detect and quantitatively assay the amount of DNA damage in large double-stranded DNA templates starting with less than 50 ng of sample DNA. This invention has utility <i>in vivo</i> for quantitating gene-specific DNA damage, measuring DNA repair rates and monitoring efficacy of anti-neoplasia therapy in patients. Additionally, this invention is useful to detect and assess risk due to mutagenic environmental hazard site, and monitor hazard site dynamics and includes a device for accomplishing these objects.</p>			

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DESCRIPTIONDETECTING DNA DAMAGE, MEASURING DNA REPAIR RATES,  
AND MONITORING DNA REPAIR ENZYME ACTIVITY

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FIELD OF THE INVENTION

This invention relates to the field of molecular biology and biochemistry. More specifically, it relates to detecting and quantitating DNA damage in animals and  
10 in cell culture, for monitoring the dynamics of DNA damage including rate of occurrence and remediation by DNA repair enzymes, and for detecting and assessing genotoxic risk in the environment.

15

BACKGROUND

Organisms are being constantly bombarded by endogenous and exogenous genotoxic agents which injure their DNA. This DNA damage, if left unrepaired, can lead  
20 to cell death, somatic mutations or cellular transformation, which at the organismal level can result in cancer, aging, and decreased immunocompetency. There is now a large amount of evidence which indicates that the repair of specific DNA lesions does not occur equally  
25 throughout the entire genome. For example, it has been shown that the DNA of actively transcribed regions is repaired more efficiently than DNA of inactive regions. This gene-specific DNA repair is due mainly to the rapid repair of the transcribed strand of actively expressed  
30 genes (Mellon et al., 1987; Mellon and Hanawalt, 1989; Smerdon and Thoma, 1990), and as a consequence can lead to the accumulation of mutations in the more slowly repaired non-transcribed strand (Chandrasekhar and Van Houten, 1994).

35

Preferential repair of DNA damage in actively transcribed genes was initially identified using a

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Southern hybridization-based assay employing T4 endonuclease V, which specifically cleaves DNA at pyrimidine dimer sites (Bohr and Okumoto, 1988). While this methodology has proven useful in the identification and study of gene-specific repair, it has the serious disadvantage of requiring a lesion-specific endonuclease to incise the DNA near the damaged nucleotide. Other disadvantages including:

- 10           -     the requirements of relatively large amounts of starting sample DNA; and
- the need for specific restriction sites flanking the DNA region of interest.

15           Another approach to determining DNA damage and repair in specific genomic DNA regions is the Taq enzyme and polymerase chain reaction (PCR) method of Govan et al., (Govan et al., 1990). This method is based on the fact that many DNA lesions can block Taq DNA  
20     polymerase, which causes in a decrease in amplification product. The method of Govan et al., however, was not very powerful because of the small size limitation on the DNA segments being amplified - less than 450 bp. Subsequently, the sensitivity such assays was increased  
25     to DNA segments of about 2 to 3 kb (Jennerwein and Eastman, 1991; Kalinowski et al., 1992). Presently the detection of DNA damage in specific gene sequences of bacterial and mammalian cells is limited to the quantitation of amplification products ranging in size  
30     from 334 bp to 3.2 kb.

#### Limitation on the Sensitivity of Prior Art Amplification Assays

35           Current PCR assay methods are not sufficient to detect DNA damage after exposure to biologically and environmentally relevant doses of genotoxic agents,

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including ionizing radiation. While the current PCR-based assay for the detection of DNA damage appears to be useful at high doses of damaging agent, it suffers from lack of sensitivity at biologically relevant doses, and therefore can not be used reliably for accurate DNA damage detection and determining DNA repair rates in humans. This is a major problem as the art currently stands. To meet these needs, the sensitivity of a DNA damage detection assay must be increased from a current detection limit of about one lesion/ $10^4$  nucleotides to one lesion/ $10^5$  nucleotides.

#### Definitions

Amplification products - are the duplicates of the template's undamaged complementary DNA strands which are detected after the amplification process.

DNA damage - is modification of a bases or sugar moiety of DNA such that the replication of the DNA sequence is interrupted at the damage site.

Gene-specific - means that the DNA involved is associated with a known gene.

Genotoxin, genotoxic agent - is any agent that directly or indirectly damages DNA. These include compounds that arise in the cell naturally, or are directly derive from the environment, or indirectly from exposure to a agent in the environment (such as another compound or ionizing radiation). May also be called a mutagen.

Quantitative long-DNA amplification - refers to the amplification of long (> 5,000 base pair) DNA templates to yield substantially only amplification products representing the intact (undamaged) complementary strands of the starting template sample.

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Template - is a double-stranded DNA that contains at least one specific primer site on each of its complementary DNA strands separated by at least 5,000 base pairs on the intact template.

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#### SUMMARY OF THE INVENTION

The present invention expands on the current art of this field in a number of important areas: 1) by establishing the conditions necessary for successfully  
10 accomplishing quantitative long-DNA amplification, i.e., greater than 5,000 base-pairs of DNA, 2) by improving sensitivity for the detection of DNA damage, 3) enabling the determination of the rate of DNA repair following a biologically relevant exposure to a genotoxic agent,  
15 including ionizing radiation, and 4) providing a means for detecting environmental hazards at the genetic level and for monitoring exposure to genotoxic agents. Additionally, the present invention does not require damage-specific endonucleases, and can yield information  
20 on the repair of several genes concurrently, and expands the ability of this art field to quantitate DNA amplification products and to detect one damaged lane in  $10^5$  DNA nucleotides.

25 A further advantage of the present invention is that it requires significantly less starting sample to detect gene-specific DNA damage than current Southern-based methods, with about a 50 to 100 fold or greater improvement in sensitivity because the present method  
30 only requires as little as 5ng to about 15ng of starting double-stranded DNA template sample.

An additional advantage is that more than one template sample may be assayed in the same quantitative  
35 amplification reaction. This allows the use of an internal control in the reaction process as well as the

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simultaneous processing of multiple different template samples.

5       The present invention involves a method of detecting DNA damage in a double-stranded DNA template by having the complementary strands of the template each have a strand-specific primer site separated by at least about 5,000 base pairs in the double-stranded DNA template molecule; combining the complementary strands of the DNA  
10       template in a mixture with primers to the strand-specific primer-site on each of the complementary strands; performing quantitative long-DNA amplification on the mixture to produce amplification products; and detecting DNA damaged of the double-stranded DNA in the template  
15       sample in its amplification products. An aspect of this method is that where the double-stranded DNA template is a gene-specific sequence of genomic DNA, the method detects gene-specific DNA damage. A further aspect of this invention is the quantitation of DNA damage,  
20       wherein, the relative amount of damaged DNA in the original template sample is quantitatively related to the inverse of the amount of amplification product from the reaction.

25       The present invention also includes a method for determining the rate of DNA repair in a living organism or in tissue culture cells by taking double-stranded DNA template samples from the system at different times, processing each sample separately; quantitating the  
30       amount of DNA amplification from each sample; and using the change in the amount of DNA amplification to determine the levels of DNA damage over time to assess the rate of DNA repair in the system.

35       The invention comprises a method for diagnosing efficacy of an anti-neoplasia therapy in a patient by determining the rate of DNA repair in a patient at at



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least two different times, and then diagnosing the efficacy of the therapy in the patient by comparing the individual rates of repair to assess the dynamics of the rates of repair over the course of time.

5

The present invention may be seen as including a device for detecting the presence of environmental genotoxic agents by detecting their effect at the genetic level. This may be accomplished by having at least two  
10 double-stranded DNA template samples with at least one of the template samples exposed to the environment (the test sample) and at least one of the template samples protected from the environment (the control sample). Another aspect of the instant device is a personal DNA  
15 mutagen exposure dosimeter with a means for attaching the dosimeter to a person, and additionally, a method of monitoring an individual's exposure to DNA mutagens over an interval of time by attaching the dosimeter to the individual for an interval of time, and then processing  
20 the device to detect DNA damage. The individual's exposure to genotoxins or DNA mutagens may then be monitored.

The invention further involves a method of detecting  
25 the presence of genotoxins (mutagens) in the environment by placing the device in an environment for a period of time effective to expose the environmental test sample to the mutagenic effects of any genotoxins present; processing the template DNA samples of the device to  
30 detect DNA damage; comparing the DNA damage in the control sample to the environmental sample to detect the presence of genotoxins in the environment. A further aspect of this object of the invention is a method of assessing the level of risk due to exposure to a  
35 mutagenic hazard in an environment by using the instant device and comparing the quantity of DNA damage in the control sample to the test sample.

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An additional aspect of the invention is a method for mapping an environmental mutagen hazard site by placing the instant device at various map locations at the site for an effective period of time; processing the template DNA samples of the device; and mapping the detection of DNA damage at the map locations to form a mutagen hazard map of the site. More particularly, this aspect includes a method for quantitative mapping of an environmental mutagen hazard site by determining the amount of DNA damage at each map location; and mapping the amount of DNA damage at the map locations to form a quantitative mutagen hazard map of the site.

DNA damage caused by the chemotherapeutic agent cisplatin may be assessed by obtaining a first DNA template sample from a patient subject to cisplatin therapy and reacting a portion of this sample with an amount of cyanide ion displacing cisplatin adducts from the DNA to form a second DNA template. When quantitative polymerase chain reaction amplification is performed utilizing primer sites separated by a least 5,000 base pairs, the cyanide-reacted cisplatin DNA or second DNA template is more amplified than the first DNA template retaining cisplatin. By comparing amplification rates of the first and second DNA templates, DNA damage induced by cisplatin may be assessed. An effective amount of cyanide to displace the cisplatin is about 1 M. The preferred cyanide salt utilized is potassium cyanide and the reaction may be overnight at room temperature. After the overnight incubation of the cyanide-reacted material, any excess cyanide and cisplatin and or cisplatin-cyanide adducts are removed, for example by dialysis. The present invention demonstrates the assessment of DNA damage for a variety of conditions utilizing minute DNA samples, e.g. 1 to 30  $\mu$ g and preliminary chain reaction primers separated by at least about 5,000 base pairs. Geneotoxin hazard sites may even be mapped by performing

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the present invention on DNA samples exposed to environmental samples from different locations of the hazard site. In one embodiment a personal DNA geneotoxin exposure dosimeter may be utilized containing two samples of double-stranded DNA templates having DNA primer sites separated by at least 5,000 base pairs. One sample is exposable to the environment and when utilized is exposed to the environment in a manner such that potential geneotoxins may interact with the contained DNA template. One sample is sealed from the environment but carried on the individual to act as a control. After exposure, performance of quantitative long-chain polymerase chain reaction according to the present invention may be utilized to assess DNA damage in the exposed sample. Additionally, certain types of DNA damage may occur which do not inhibit polymerase chain reaction amplifications. The present invention includes methodology to quantitate DNA damage in at least some of those cases, for example, as with the formation of 8-oxo-deoxyguanosine or formamidopyrimidine. This involves converting those damaged sites to DNA strand breaks that do inhibit DNA amplification.

The methods of the present invention may also be used to monitor genetic damage due to self-induced genotoxin exposure such as smoking, sunlight exposure or the aging process. This would, of course, entail control DNA samples for purposes of amplification rate comparisons. Such control samples, for the usual DNA damage inhibiting amplification, require an individual's pre-exposure DNA. A control for DNA damage not inhibiting amplification would be obtained by converting such DNA damage point to, e.g., DNA strand breaks, as mentioned herein for assessing damage relating to 8-oxo-deoxyguanosine or formamidopyrimidine.

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While a number of objects and advantages are disclosed above, it is well within the ability of one skilled in the art, in view of the present teachings, to conceive of additional objects and advantages that are still within the scope and spirit of the invention as a whole as disclosed herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

10        **FIG. 1.** Schematic representation of the detection of DNA damage double-stranded DNA in a template sample containing both damaged and undamaged template using quantitative long-DNA amplification.

15        **FIG. 1A.** Theoretical amplification (left axis) and lesion frequency (right axis) versus fragment size at a fixed amount of DNA damage (Effect of  $10 \text{ J/m}^2$  of UV light on Amplification).

20        **FIG. 2.** Long-DNA amplification fragments from the human hypoxanthine phosphoribosyltransferase gene locus (*hprt*).

25        **FIG. 3.** Amplification of long-DNA templates: from the human *hprt* gene the 2.7 kb, 6.2 kb, 10.4 kb, and 15.4 kb fragments in lanes 2-4 and 9 respectively; from the  $\beta$ -globin gene the 13.5 kb fragment in lanes 5 & 8, the 17.7 kb fragment in lanes 7 & 11 and the 24 kb fragment in lane 12; and the entire 16.2 kb human mitochondrial genome in lanes 6 & 10. M1 is a 1 KB ladder standard and  
30        M2 is a  $\lambda$ -phage/Hind III standard.

35        **FIG. 4.** Table of results from Example 2 showing relative amplification product ratio (Rel. Amp) and lesion frequency for increasing length of template.

**FIG. 5A.** The effect of cycle number on the amount of amplification product for 15.4 kb human *hprt* fragment.

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FIG. 5B. The effect of cycle number on the amount of amplification product for 17.7 kb  $\beta$ -globin fragment.

FIG. 5C. The relative amplification of the 17.7 kb fragment at 27 cycles as a function of template concentration from 0 - 30 ng.

FIG. 6. Ethidium bromide stained gel of amplification products generated from UV-damaged human genomic template (irradiated with  $10\text{J/m}^2$  of UVC) and nondamaged genomic DNA in the practice of the present invention.

FIG. 7. Effects of  $10\text{J/m}^2$  UV light on the relative amplification of various sizes of DNA template. Error bars for the 2.7 kb, 15.4 kb, and 17.7 kb templates is the mean  $\pm$  S.E. of three separate long-DNA amplifications reactions quantified two-times for each reaction (total  $n=6$ ).

20

FIG. 8A and FIG. 8B. Effects of UV light on the relative amplification of 15.4 kb *hprt* human genomic DNA template (FIG. 8A) and resulting lesion frequency (FIG. 8B).

25

FIG. 8C and FIG. 8D. Effects of UV light on the relative amplification (FIG. 8C) of a 17.7  $\beta$ -globin kb human genomic DNA template, and resulting lesion frequency (FIG. 8D).

30

FIG. 9. Table showing relative amplification product ratio (Rel. Amp) and lesion frequency for increasing length of template and exposure to a DNA damaging agent.

35

FIG. 10. UV Repair kinetics in normal cells and repair deficient (XPA) cells.

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FIGs. 11A and 11B. DNA repair kinetics. FIG. 11A. in transformed human fibroblasts (■ = inactive  $\beta$ -globin; ● = *hprt*; -- = rate of transcribed strand repair). FIG. 11B. in lymphoblastoid cells from a normal donor

5 GM01989B; GM02344A is from a patient with xeroderma pigmentosum group A; P2 is a lymphoblastoid cell line from a patient with colon cancer a homozygous mutation in a mismatch correction gene, *hPMS2*; P8 is a lymphoblastoid

10 cell line from a patient with a heterozygous mutation in a mismatch correction gene, *hMSH2*; P7 is apparently normal lymphoblastoid cell line.

FIGs. 12A and 12B. Formation of hydrogen peroxide-induced DNA damage in mitochondrial DNA and a nuclear

15 gene from human fibroblasts. FIG. 12A shows relative amplification as a function of hydrogen peroxide concentration. FIG. 12B shows the lesion frequency.

FIG. 13. Repair kinetics of oxidative DNA damage. Histograms show relative damage in the beta-globin gene and mitochondrial genome as a function of time after

20 hydrogen peroxide treatment.

FIG. 14. Glucose oxidase-induced DNA damage in human fibroblasts. Graph shows the lesion frequencies in the beta-globin gene and mitochondrial genomes.

25

FIG. 15. Oxidative DNA damage in primary cultures of human vascular cells. Graph shows relative amplification of mitochondrial DNA versus beta-globin

30 DNA.

FIG. 16. Detection of 8-oxo-deoxyguanosine adducts using FPG and QPCR. Histograms show the 8-oxoG levels in untreated and acridine orange (AO) plus white light

35 treated human cells.

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FIG. 17A and FIG. 17B. Repair kinetics of cisplatin-DNA adduct in human cells. Histograms show relative amplification following a 2 hr 150  $\mu$ M cisplatin treatment. Solid bar is relative amplification of a nondamaged control. (FIG. 17A =  $\beta$ -globin; FIG. 17B = *hprt*)

FIGs. 18A and 18B. Detection of benzo[a]pyrene diol epoxide-DNA adducts in human cells. Human cells were treated with benzo[a]pyrene diol epoxide (BPD) for one hour and the DNA was used for amplification of either mitochondria, *hprt* or beta-globin fragments. FIG. 18A gives relative amplification and FIG. 18B gives lesions/10 kb.

15

The drawings are not necessarily to scale and certain features of the invention may be exaggerated in scale or shown in schematic form in the interest of clarity and conciseness. It will be readily apparent to one skilled in the art that various substitutions and modifications may be made to the invention disclosed herein without departing from the scope and spirit of the invention.

25

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention includes a method detecting DNA damage in a sample of double-stranded DNA template (see FIG. 1). In the preferred embodiment, the present method uses at least two double-stranded DNA template samples, generally, a control sample and a test sample. The control sample may be a duplicate of the test sample which has not been exposed to DNA damage, or it may be a test sample against which a different test sample is compared. In practice, a test sample of double-stranded DNA template is taken from a system of interest. The system of interest could be an *in vitro* system, such as

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cell or tissue culture, or an *in vivo* system, such as a patient, or an environmental system, such as a chemical spill site. The template is selected such that its individual complementary strands each have a strand-specific primer site, and the primer-sites are separated by at least about 5,000 base pairs in the intact template DNA. Using purified DNA, this method has been used to amplify a 30,000 base pair DNA template. The choice of using purified DNA or not is left to the artisan. For example, from a biological system, chromatin rather than purified DNA may serve the artisan's purpose, whereas, in a chemical system (like a dosimeter) purified DNA template is readily available. If the DNA template used in the method represents a gene-specific DNA sequence, then the method detects gene-specific DNA damage. The amount of double-stranded DNA template necessary in this method is about 50 ng or less of human genomic DNA (equivalent to about 10,000 cells), with about 5ng to about 15ng being the low range of starting template DNA.

20

The template sample or its complementary strands are placed in a proper mixture with an excess of primers to the strand-specific primer-sites. Then quantitative long-DNA amplification is performed on the mixture, to produce amplification products. The amplification products represent substantially only the undamaged individual strands. Any damaged individual strands are substantially not amplified, and therefore comprise negligible amplification product and do not appear in a standard gel analysis.

30

Typical reactions conditions consist of 50 pmol of each primer, 200 uM dNTPs, 1.5 mM MgCl<sub>2</sub>, 50 mM Tris-Cl, pH 8.0, 2.5 units Ampli-Taq, and 50 ng of purified human cellular DNA in a 50 ul reaction volume. Amplifications may be performed in the Perkin-Elmer 9600 thermocycler which is specially designed for quantitative

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amplifications. Amplifications are performed by initially denaturing the DNA at 94°C for 4 minutes, followed by 30 cycles of 94°C, 30 seconds denaturation followed by annealing at 61°C for 1 minute, and extension  
5 at 72°C for 2 minutes. The final extension step is allowed to continue 7 minutes.

Amplification product is then characterized using any of a number of methods available to one skilled in  
10 the art. Such methods include polyacrylamide gel electrophoresis, electrochemiluminescence, radioisotope incorporation and autoradiography and Betascope™ imaging (Betagen, Waltham, MA).

15 The detection of DNA damage in the test sample is accomplished by comparing the results of the characterization of the amplification product of the test sample to the amplification product of a control sample of the same template processed in the same manner as the  
20 test sample. If the test sample template yields less amplification product than the control sample, the test sample template DNA sustained damage. If the test sample template and the control sample template yield substantially the same amount of amplification product,  
25 the test sample template DNA did not sustain detectable DNA damage. In no case should the test sample template yield more amplification product than the control sample template, as this would indicate a problem with the assay.

30

The amount of DNA damage in the test sample template may be quantitated by comparing the amount of amplification product from a control template sample against the amount of amplification product from the test  
35 sample template. This may be accomplished by using any of a number of methods known to the skilled artisan for quantitating an amount of DNA. These methods include:

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**A. Gel electrophoresis and radioisotope imaging.**

Gel electrophoresis is based on the incorporation of dCTP- $\alpha$ -[<sup>32</sup>P] radiolabeled nucleotides into the amplification products during the amplification reaction. The amplification products are then separated from unincorporated dNTPs by electrophoresis in an agarose gel. The agarose gel is then dried and the amount of radioactivity in each band is determined thorough the use of a 2D-radioisotope imaging system such as the Betascope 603 Blot analyzer from Betagen (Waltham, Mass). This assay is extremely sensitive since the specific activity of the product can be readily adjusted by increasing the amount of radioactive tracer.

**B. High Performance Liquid Chromatography.** Katz, et al. (Katz et al., 1992), incorporated herein by reference. Amplification products, without any further manipulation, are applied to an anion-exchange column (TSK DEAE-NPR) and eluted with a binary mobile phase of two buffers. A guard column is used in series with the DEAE column to avoid clogging from genomic DNA. The gradient program is dependent upon the specific size of amplification products which are to be resolved. DNA is detected using a UV detector set at 260 nm. The amount of amplification products is determined by previously described standard DNA assays.

**C. Electrochemiluminescence (ECL).** ECL, is a novel quantitation assay for PCR products which has been developed by Perkin-Elmer. Several different formats have been developed. Here a format was used in which amplification product is tagged on one end with a special electroch miluminescent probe (TBR) and is tagged on the other end with biotin, through the use of appropriately modified PCR primers. The

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product is captured using streptavidin coated magnetic beads and the amount of product is quantitated in a special instrument, the QPCR System 5000 (Perkin-Elmer, Norwalk, CT), which accurately measures the electrically-stimulated luminescence of the chemical probe.

The ability to amplify large DNA fragments allows for increased sensitivity as shown in FIG. 1A. Recently methods have been reported for the amplification of long PCR fragments (Cheng et al., 1994). Larger DNA fragments will increase the sensitivity as shown in a theoretical plot of the effect of a fixed fluence of UVC light ( $10 \text{ J/m}^2$ ) on amplification as a function of fragment size, where increasing lesion frequency is shown on the right axis. For example,  $10 \text{ J/m}^2$  of UVC light produces about 0.2 photoproducts per 2.7 kb and decreases amplification to 80% of a nondamaged control. However, amplification of a 14 kb fragment would be decreased to 37% (one blocking lesion per strand) and amplification of a 30 kb fragment is reduced to around 11% of a nondamaged control.

In another embodiment, the present invention includes a method for determining the rate of DNA repair in a cellular system by taking a sample of a double-stranded DNA template from the system at at least two different times. After processing and quantitating DNA damage in each sample separately, the rate of DNA repair is determined as the change in the amount of amplification product between the samples over the course of time.

This embodiment is useful for diagnosing efficacy of an anti-neoplasia therapy in a patient. Efficacy of an anti-neoplasia therapy may be assessed by monitoring the therapy's effect on the rate of DNA repair in the

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patient. This is accomplished by taking an initial set of samples of a double-stranded DNA template from the patient and determining a rate of DNA repair as described above. Then, after an appropriate course of time, taking  
5 a subsequent set of samples from the patient and again determining a rate of DNA repair. Efficacy of the therapy is diagnosed by comparing the DNA repair rate at the two sampling times. An increasing DNA repair rate, a decreasing DNA repair rate and/or a stable repair rate  
10 may be determined using the present method.

Another embodiment of the present invention is a device for detecting the effect of environmental genotoxins. The device comprises at least one double-  
15 stranded DNA template sample, to serve as an environmental test sample. One or more additional double-stranded DNA template samples may also be placed in the device to serve as a control sample. The test sample is to be exposed to the environment of interest,  
20 but the control sample is not to be so exposed. The test sample template DNA is held in a container which is pervious to the environment or agent in the environment of interest. The control sample is held in a container which is not pervious to the environment or held separate  
25 from the environment.

Presence of a genotoxic hazard in an environment may be detected using the device of the present invention. Environmental genotoxins are detected by their effect on  
30 the exposed test sample relative to the control sample or some other standard. The test sample will show evidence of DNA damage if a sufficient level of genotoxin is present in the environment to cause DNA damage. This is accomplished by exposing the device to the environment of  
35 interest for an effective period of time, processing the template DNA samples of the device to detect DNA damage in the sample template. If the amount of DNA damage in

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the amplification product is quantitated, then an assessment of the level of risk due to exposure in the environment may be made by comparing the quantity of DNA damage over the period of exposure against a relevant exposure standard or toxicity table.

Additionally, an environmental hazard site may be mapped as to location and risk level of agents effecting DNA damage by placing the instant device at various locations in the environment for an effective period of time, processing the template DNA samples of the devices and quantitating the amount of DNA damage as described herein, and then assessing and plotting the level of risk at each location on a site map. By quantitating the amount of DNA damage at each location, rather than just the presence of a genotoxic effect, a more dynamic understanding of the hazard site can be developed, which is useful in assessing overall risk and planning containment and clean-up priorities for the site.

Further, the instant device may be carried on one's person and use as a personal dosimeter for exposure over time to genotoxic effects.

An effective period of time for exposing the instant device can vary from a very few minutes for ionizing radiation (e.g., radiation therapy) to months for an environmental site assessment. The skilled artisan is able to make an initial assessment of necessary exposure time based on the toxicity, concentration and flux of the agent and other prevailing environmental conditions.

Where it is recited that there are alternative materials and methods are available to one skilled in the art, which alternative the skilled artisan elects will be influenced by the resources available and the degree of familiarity of the artisan with the various alternatives.

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One skilled in the art in view of this disclosure will be able to practice this invention using equivalent materials and methods of the artisan's own preference.

- 5           Tables 1-4 summarize various amplification products, damaging agents, cell lines and repair kinetics demonstrated as used in the following Examples.

Table I. Amplification products currently under study

10

	Gene	size (kb)	Cell origin
	Active		
	hprt	15.4	human
	$\beta$ -polymerase	12.2	human
15	$\beta$ -polymerase	6.2	mouse
	mitochondria	16.2	human
	mitochondria	16.2 (in development)	mouse
	p53	in development	human
20	Inactive		
	oxytocin receptor	14.4	human
	$\beta$ -globin	17.7	human
	$\beta$ -globin	8.7	mouse

25

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Table II. Detection of gene-specific damage using QPCR

Damaging agent		Comments
	asbestos	generates reactive oxygen species; cause of mesothelioma
	benzo[a]pyrene diol epoxide	common environmental carcinogen
5	chlorambucil	widely used anti-cancer agent
	cisplatin	widely used anti-cancer agent
	glucose oxidase	produces hydrogen peroxide
	hydrogen peroxide (H <sub>2</sub> O <sub>2</sub> )	reactive oxygen species
	paraquat	common herbicide; generates reactive oxygen species
10	TPZ (tirapazamine)	increases the effectiveness of cisplatin
	UV	cause of skin cancer

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Table III. Cell lines examined by QPCR

	Cells	Organism	Damaging agent
	transformed fibroblasts	human	UV <sup>a</sup> , BPDE <sup>b</sup> , cisplatin, oxidants <sup>c</sup>
5	transformed epithelial cells	human	chlorambucil
	transformed mesothelial	human	asbestos
	lymphoblastoid	human	UV
10	primary lymphocytes	human	UV, TNF- $\alpha$
	primary endothelial	human	hydrogen peroxide
15	transformed endothelial	human	chlorambucil
	neutrophils	mouse	LPS <sup>d</sup>

a, UV = ultraviolet light, 254 nm

b, BPDE = benzo[a]pyrene diol epoxide

c, oxidants= hydrogen peroxide, glucose oxidase,  
paraquat, TPZ (tirapazamine)

d, LPS = lipopolysaccharide



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Table IV. Repair Kinetics of Human Cells Studied by QPCR.

	Mutant	Cell type	Damaging Agent	Comments
5	WT	transformed fibroblast	UV	•rapid repair intratranscribed gene
			BPDE	•transcribed gene damaged more
			cisplatin	•repaired slower than UV
			H <sub>2</sub> O <sub>2</sub>	each agent causes
			glucose oxidase	more mt DNA which is poorly repaired
10	WT	transformed mesothelial cells	asbestos	
	WT	lymphoblastoid	UV	•rapid repair
	WT	primary lymphocytes	UV	
	WT	smooth muscle	H <sub>2</sub> O <sub>2</sub>	
15	WT	primary umbilical vein	H <sub>2</sub> O <sub>2</sub>	
	WT	endothelial cell	H <sub>2</sub> O <sub>2</sub>	
	XPA	fibroblast	UV	•repair deficient
	XPA	lymphoblastoid	UV	•repair deficient
	XPC	lymphoblastoid	UV	•slow repair in non-transcribed genes
20	PMS2 <sup>-</sup> (P2)	lymphoblastoid	UV	•slow repair
	PMS2 <sup>+/-</sup> (P7)	lymphoblastoid	UV	•slow repair

25

The following examples are intended as illustrations of the practice of this invention and are not meant to limit the scope of the invention.

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**EXAMPLE 1****Isolation and Digestion of Genomic DNA**Isolation of genomic DNA.

5           Lysis buffer (2% SDS, 0.5 M NaCl, 0.05 M EDTA, 50 mM  
Tris-HCl, pH 7.5) containing 200 ug/ml proteinase K was  
added to thawed cell pellets (3.0 ml/1-5 × 10<sup>6</sup> cells) and  
was incubated overnight at 37°C. The lysates were  
10       extracted twice with PCI, and once with CI. The top  
aqueous phase was removed to an autoclaved 15 ml Corex  
tube and 1/10 volume of 3 M sodium acetate and 2.5  
volumes cold 100% ethanol were added. The DNA was  
precipitated at -20°C for > 30 minutes, and then  
15       collected by centrifugation at 4°C for 30 minutes at  
8,000 rpm. Pellets were rinsed in 70% ethanol, dried in  
air, and resuspended in TE buffer.

Digestion of genomic DNA.

20           DNA was incubated with 3-5 Units/ug DNA of BamHI  
overnight at 37°C, followed by 2 PCI and 1 CI extraction.  
DNA was then precipitated in 2.5 volumes of 100% ethanol,  
washed with 70% ethanol, and resuspended in TE buffer.  
25       DNA concentration was quantitated by fluorometry using  
Hoechst dye 33258.

**EXAMPLE 2****Amplification of Long-DNA Templates**

30           Previously, the longest DNA template amplified using  
PCR is reported as a 2.7 kb fragment of the *hprt* gene  
from oligonucleotide b to e (see FIG. 2). The present  
example describes the quantitative long-DNA amplification  
35       of 2.7 kb, 6.2 kb, 10.4 kb, and 15.4 kb DNA fragments  
from *hprt* locus (FIG. 2), and 17.7 and 24 kb fragments  
from the  $\beta$ -globin gene and the entire 16.2 kb human

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mitochondria genome. These amplifications were accomplished using XLPCR<sup>TM</sup> conditions (Perkin Elmer/Roche).

5           FIG. 3 is a photograph of ethidium bromide stained agarose gels in which 50 ng of genomic DNA was amplified using various primer sets and special XLPCR<sup>TM</sup> reagents and conditions. Specifically, 50 ng of DNA was added to a reaction mixture containing dNTPs (200  $\mu$ M), glycerol  
10   (8%), DMSO (2%), Tricene-acetate (25 mM, pH 8.0), potassium acetate (25 mM), magnesium acetate (1 mM), and 10 pmol each primer. After prewarming to 75°C for 90 seconds a combination of thermostable polymerases (rTth, 1 unit, and Vent with rTth > > Vent) were added.  
15   After a 94°C 1 minute denaturation the reactions were subjected to 36 cycles of 94°C, 15 sec, 68°C for 12 minutes. A 10 $\mu$ L aliquot of each reaction mixture was loaded on to a 0.6% agarose gel (Bethesda Research Labs) for lanes 1 to 7, or a 0.4% SeaKem<sup>TM</sup> agarose gel for  
20   lanes 8 to 13. Gels were electrophoresed at 100 V/13 cm for 4 hours.

FIG. 3 shows amplification of long-DNA templates: from the human *hprt* gene the 2.7 kb, 6.2 kb, 10.4 kb, and  
25   15.4 kb fragments in lanes 2-4 and 9 respectively; from the  $\beta$ -globin gene the 13.5 kb fragment in lanes 5 & 8, the 17.7 kb fragment in lanes 7 & 11 and the 24 kb fragment in lane 12; and the entire 16.2 kb human mitochondrial genome in lanes 6 & 10. M1 is a 1 KB  
30   ladder standard and M2 is a  $\lambda$ -phage/Hind III standard. The results of this example are given in the table of FIG. 4.

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**EXAMPLE 3****Quantitative Amplification of Long-DNA Templates**

Quantitative long-DNA amplification conditions,  
5 i.e., conditions in which the amount of amplification is  
directly proportional to the amount of added template,  
were determined by examining the amount of amplification  
product at various cycles of the amplification reaction  
at different amounts of added template. The results of  
10 this determination for the quantitative conditions used  
for amplification of the 15.4 kb *hprt* fragment and the  
17.7 kb  $\beta$ -globin fragment are shown in FIG. 7.

FIG. 5A shows the effect of cycle number on the  
15 amount of amplification for the 15.4 kb human *hprt*  
fragment. FIG. 5B shows the effect of cycle number on  
the amount of amplification for the 17.7 kb  $\beta$ -globin  
fragment. FIG. 5C shows the relative amplification of  
the 17.7 kb fragment at 27 cycles as a function of  
20 template concentration from 0 - 30 ng.

**EXAMPLE 4****Detecting and Quantitating Long-DNA Template Damage**

25 Various length template test samples of purified  
human genomic DNA were irradiated with  $10\text{J/m}^2$  of UVC  
light to cause damage to the DNA. These irradiated  
template test samples and corresponding nonirradiated  
template control samples were processed according to the  
30 practice of the present invention. Amplification  
products were radiolabeled by the incorporation of  
[ $\alpha$ - $^{32}\text{P}$ ]-dATP during the amplification process. The  
amplification products for each sample were characterized  
using agarose gel electrophoresis, ethidium bromide  
35 staining and autoradiography (see FIG. 6). DNA damage in  
the test sample template was detected as lesser intensity  
of ethidium bromide staining of amplification products

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from the test sample relative to the control sample. In FIG. 6, quantification of DNA damage was determined by radioisotope imaging using a PhosphorImager<sup>TM</sup> and Image Quant<sup>TM</sup> (Molecular Dynamics) software.

5

Substantially, only the nondamaged templates in a sample will participate in the quantitative amplification reaction. Therefore, this assay is a general measure the fraction of template molecules which contain no damage. This is accomplished by quantifying the amount of amplification product ( $A_D$ ) from test sample and dividing it by the amount of amplification product ( $A_0$ ) from an equal amount of untreated control sample. Assuming a random distribution of lesions, and using the Poisson equation [ $f(x) = e^{-\lambda} \lambda^x / x!$ ] for the zero class molecules (i.e., those containing no damage),  $f(0) = e^{-\lambda}$ , where  $\lambda$  = average lesion frequency, the lesion frequency per genomic strand can be calculated:  $\lambda = -\ln A_D/A_0$ . Therefore, the assay measures the average lesion frequency per strand for the two template strands in the genomic segment of interest.

Using the Poisson expression of the zero class the lesion frequency ( $L$ ) was determined per DNA fragment as  $L = -\ln A_{UV}/A_0$ , where  $A_{UV}$  = the amount of amplification following UV damage and  $A_0$  is the amount of amplification of the nondamage control. In order to compare the relative error associated with each fragment size, the amount of damage was normalized to one kb by dividing each fragment by its total length.

The relative amplification product was determined for various length templates and is displayed in FIG. 7. As can be seen this dose of UV while decreasing the amplification of the 2.7 kb fragment only 30% decreased the amplification of the 15.4 hprt and 17.7 globin fragment 85% and 92% respectively. These data followed

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the hypothetical plot shown in FIG. 4, and clearly demonstrated the utility of long-DNA templates for increased sensitivity to detect and quantitate DNA damage.

5

#### **EXAMPLE 5** **Reproducibility**

Dose-response curves were generated to establish the reproducibility of the gene-specific assay and the lowest detectable UV dose to human cells (FIG. 10) using DNA extracts from cells which had been exposed to various doses of UV light. Quadruplicate sets of culture dishes plated with human cells were treated with 0, 2.5, 5, 10, and 20 J/m<sup>2</sup> of UV light at 254 nanometers. The DNA was harvested immediately and used in two separate quantitative long-DNA amplification reactions. Each amplification reaction was analyzed twice. The points represent the mean of n=16 +/- S.D. determinations. The amount of template DNA damage was determined from the relative decrease in amplification product as described above. As in FIGS. 8A-D, the damage resulting from 2.5 J/m<sup>2</sup> of UV light was easily detected (see table, FIG. 9). Furthermore the precision at which the damage was detected is 5-10% CV. These results demonstrated predictable dose-response with high precision at low doses.

30

#### **EXAMPLE 6** **Determination of DNA Repair in** **Actively Growing Human Cells**

Template DNA from the active *hprt* gene and the inactive  $\beta$ -globin gene was used in the long-DNA amplification assay to determine DNA repair in actively growing human cells. DNA repair deficient xeroderma pigmentosum (group A) cells were used as an external

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control for comparison. Quadruplicate plates of normal human cells or repair deficient cells from a patient with xeroderma pigmentosum (group A) were treated with  $10 \text{ J/m}^2$  of UV light and harvested immediately or allowed 8 hours for repair. For normal cells the DNA was harvested and used in two separate long-DNA amplification reactions. Amplification product from each amplification reaction was analyzed twice. The results of this analysis are shown in FIG. 10, where the points represent the mean of  $n = 16 \pm \text{S.D.}$  determinations for normal cells. XPA data represent the mean of one long-DNA amplification reaction from four separate DNA samples. FIG. 10 demonstrates that in normal cells there was significant repair in the active *hprt* gene, but little or no repair in the inactive  $\beta$ -globin gene. Further, there was little or no repair observed for either of these two genes in repair deficient XPA cells.

Having determined DNA damage in a system at two different times, the rate of DNA repair was determined as the relative difference in the amount of amplification product at the two times over the difference in time.

Repair kinetics in different mutant cell lines. In order to validate the use of this novel QPCR assay the repair kinetics of UV-induced DNA damage in a 15.4 kb fragment from the expressed human *hprt* gene and a 17.7 kb fragment from the non-expressed  $\beta$ -globin gene from several different human cell lines were characterized. Human cells were treated with UV light ( $10 \text{ J/m}^2$ ). The DNA was extracted using QIAamp® Tissue Kit (QIAGEN, Inc, Chatsworth, CA). In this approach the DNA is extracted from cells without the use of harsh organic compounds which can induce significant amounts of oxidative DNA damage. Briefly the frozen cell pellet is lysed in a chaotropic buffer supplied by the manufacturer which contains Proteinase K. The DNA is precipitated and loaded

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on to a spin column. The DNA is eluted in a TE buffer (10mM Tris-Cl, 1mM EDTA). The DNA is diluted and its precise concentration is determined by ethidium bromide fluorescence. These DNA are used in the QPCR assay. Long fragments were amplified using a XLPCR kit from Perkin-Elmer and rTth thermostable enzyme supplied with the kit. [p<sup>32</sup>]- $\alpha$ -dATP was added to each reaction as a tracer and the radiolabeled fragments are separated on 0.6% vertical agarose gels. Radiolabeled amplification products were quantified from dried agarose gels using a Phosphor Imager 425 and ImageQuant<sup>TM</sup> software (Molecular Dynamics). Lesion frequencies were calculated by quantifying the amount of amplification ( $A_D$ ) from genotoxin-treated sample and dividing it by the amount of amplification ( $A_O$ ) from an equal amount of untreated control sample. Assuming a random distribution of lesions, and using the Poisson equation [ $f(x) = e^{-\lambda} \lambda^x / x!$ ] for the zero class molecules (ie, those containing no damage),  $f(0) = e^{-\lambda}$ , where  $\lambda$  = average lesion frequency, the lesion frequency per genomic strand can be calculated as,  $\lambda = -\ln A_D/A_O$ .

Repair of UV-induced photoproducts following 10 J/m<sup>2</sup> in an SV40- transformed fibroblast is shown in FIG. 11A for both the expressed *hprt* gene (●) and the nonexpressed  $\beta$ -globin gene (■) where each data point is the  $N = 4 \pm \text{SEM}$ . These data clearly show that the non-expressed  $\beta$ -globin gene ( $t_{1/2} = 23.5$  hr) is repaired significantly slower than the *hprt* gene ( $t_{1/2} = 8.3$  hr). The dashed line is the calculated rate of repair for the actively transcribed strand of the *hprt* gene ( $t_{1/2} = 5.0$  hr). Repair kinetics have also been performed in several adenovirus transformed human lymphoblastoid cell lines. These include: GM01989B is apparently normal; GM02344A is from a patient with xeroderma pigmentosum group A; P2 is a lymphoblastoid cell line from a patient with a homozygous mutation in a mismatch correction gene, *hPMS2*; P8 is a



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lymphoblastoid cell line from a patient with a heterozygous mutation in a mismatch correction gene, *hMSH2*; P7 is apparently normal lymphoblastoid cell line. P2, P7, and P8 were obtained in collaboration with Dr. Isabel Mellon (University of Kentucky) who is examining the repair kinetics of these cell lines using the pyrimidine dimer specific gene-specific assay. The results presented in FIG. 11B show clear differences in gene-specific repair among several individuals and also among different cell types (For simplicity only repair in the  $\beta$ -globin gene is shown, FIG. 11B). Note that repair in the fibroblast cell line is slower as compared to the lymphoblastoid cell line (GM019889B). The XPA line (GM02344A) shows the slowest repair kinetics and is consistent with published information on XPA cell lines. Also note that repair in P7 is faster than the mismatch defective line P2. These results are consistent with unpublished gene-specific repair kinetics from Dr. Mellon's laboratory.

20

**EXAMPLE 7****Multiplex DNA Damage Detection  
Simultaneous Analysis of DNA Damage in  
More Than One Template**

25

For multiplex quantitative long-DNA amplification, samples contained 30-60 ng of DNA incubated in GeneAmp PCR buffer II (50 mM KCl, 10 mM Tris-HCl, pH 8.3), 1.5 mM  $MgCl_2$ , 200  $\mu$ M each dNTP, 2 uCi dCTP- $\alpha$ - $[^{32}P]$ , 0.05 to 1.0  $\mu$ M of each primer, and 2.5 U AmpliTaq DNA Polymerase (Perkin-Elmer) in a 50  $\mu$ l reaction volume. In a Perkin-Elmer GeneAmp PCR System 9600 thermocycler, the samples were denatured at 94° for 4 min and underwent 13 cycles of denaturation at 94° for 15 sec, with a 40 sec ramp to primer annealing at 48° for 30 sec, and extension at 72° for 2 min, before a final 7 min extension at 72°. Following the amplification reaction, the samples were

30

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run on a 1% vertical agarose gel, dried, and quantified by Betascope radioisotope imaging (see FIG. 3).

5 In this example, the concentration of the two primer sets have been titrated so that approximately equal amounts of amplification products were produced from each template sample. We have found that amplification of one product influences the amplification of the other product in a multiplex amplification reaction. Therefore, the  
10 relative amounts of the two primer sets were worked out empirically to produce equal amounts of each amplification product.

15 In a multiplex amplification reaction, to ensure that the selected primers produce the desired size products in a quantitative manner it is essential that two important parameters, template concentration and number of PCR cycles, be examined prior to any damage quantitation studies. The synthesis of the amplification  
20 product is ultimately linked to the amount of template and the number of amplification cycles. Amplification goes through three discrete phases: 1) the product increases exponentially with cycle number, 2) the product increases arithmetically with cycle number, and 3) the  
25 product begins to approach the amount of primers, and the product will not increase or will actually decline with increased cycles. Hence, more cycles is not necessarily better for quantitative long-DNA amplification since it is essential that the amount of product is proportional  
30 to the amount of template. Therefore, all quantitative long-DNA amplifications must be performed under conditions where product concentration increases in a known manner. Generally, after 18 cycles of amplification, twice the amount of template does not  
35 yield twice the amount of product for each gene.

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For gene-specific assay it is essential that the amount of amplification product increases exponentially with increasing cycles and that the amount of amplification product is dependent upon the template concentration. Therefore, it is preferred that the amplification reactions run for about 13 PCR cycles (Van Houten et al., 1993).

**EXAMPLE 8. Detection of Oxidative DNA damage in Human cells.**

Formation and repair of oxidative DNA damage in the nucleus and mitochondria of human fibroblasts after hydrogen peroxide. Reactive oxygen species (ROS) are produced by a wide variety of physical and chemical agents, and can also arise endogenously via leakage of oxygen from the electron transport in the mitochondria and from other cellular biochemical processes. Whether DNA damage by ROS occurs heterogeneously throughout the human genome, and whether this damage is repaired, were examined. Human SV40-transformed fibroblasts (SVNF) were treated with 0-400  $\mu\text{M}$   $\text{H}_2\text{O}_2$  for 1 hour. The DNA was extracted using a QIAGEN columns and used for amplification of a 16.2 kb mitochondrial gene fragment (●) and 17.7 kb  $\beta$ -globin gene fragment (■) (FIG. 12A and 12B). FIG. 12A shows the decrease in amplification as a function of  $\text{H}_2\text{O}_2$  concentration, FIG. 12B shows the lesions/10kb as a function of  $\text{H}_2\text{O}_2$  concentration. There was a 2-3-fold increase in damage to the mtDNA as compared to a nuclear gene. Since ROS generates a wide spectrum of DNA damages it was necessary to examine what types of DNA lesions inhibit the thermostable polymerase (rTth) used in these experiments. Single-strand breaks have been suggested to make up 25-50% of all damage following ROS and since single strand breaks are absolute stops to the polymerase this lesions is efficiently detected using quantiative amplification assay. We have

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also found that we can detect 100% of one prominent base damage lesion, thymine glycol (data not shown).

Data from a repair experiment is shown in FIG. 13.

5    Triplicate plates of SVNF were treated with 200 or 400  
      $\mu$ M of hydrogen peroxide ( $H_2O_2$ ) for 1 hour. Cells were  
     immediately harvested or were allowed 1.5 or 3 hours for  
     repair. The DNA was extracted and used for amplification  
10    of a 16.2 kb mitochondrial fragment (open bars) and 17.7  
     kb  $\beta$ -globin gene fragment (hatched bars). These data show  
     that the mitochondrial DNA suffers more damage than a  
     nuclear gene and that little or no damage was repaired in  
     the mitochondrial DNA. Note that complete repair of the  
15     $H_2O_2$  treatment.

Taken together, these data clearly show that the  
quantitative amplification assay can accurately measure  
the formation and repair of DNA damage resulting from  
20    ROS. The surprising result that mitochondrial DNA is  
     extensively damaged and not repaired after ROS suggested  
     that this organelle might be a critical toxicological  
     target for ROS and other chemicals which interact with  
     the mitochondria. If mt DNA damage is extensive and not  
25    repaired, then it would be expected to inhibit  
     transcription of mt genes which are essential for  
     electron transport during oxidative phosphorylation.

Glucose Oxidase-induced DNA damage in human

30    fibroblasts. Treatment of cells with one relative high  
     dose of  $H_2O_2$ , while effectively producing DNA damage, may  
     not accurately recapitulate *in vivo* conditions.  
     Therefore a  $H_2O_2$  generating system, glucose oxidase (GO)  
     was used, so that  $H_2O_2$  was generated at a constant low  
35    level over a period of time. In this experiment human  
     SVNF were treated in triplicate in serum-free media  
     containing indicated concentrations of GO for one hour.

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DNA was extracted using QIAGEN columns and the 16.2 kb mitochondrial (■) 17.7 kb  $\beta$ -globin ( ) fragments were amplified. The relative amounts of amplification were used to calculate lesions frequencies (FIG. 14;  $n = 4 \pm$  S.D.). These data indicate that mt DNA is damaged more than nuclear DNA by treatment with a continuous low dose of  $H_2O_2$ .

10        Oxidative DNA damage in primary cultures of human vascular cells. In collaboration with Drs. Runge and Boor a series of experiments using human vascular cells have been initiated. In this experiment, human umbilical vein endothelial cells (HUVEC) were treated with the  
15        various concentrations of  $H_2O_2$  for one hour (FIG. 15). The DNA was extracted and used for QPCR of the 17.7  $\beta$ -globin (open bars) and 16.2 mitochondrial DNA (hatched bars) fragments. These data indicate that like  
20        transformed fibroblasts, mtDNA in vascular endothelial cells is damaged more than nuclear DNA. These data strongly support the hypothesis that the mitochondria is a critical target for ROS-induced injury in vascular tissue.

25        **EXAMPLE 9. Detection of 8-oxo-deoxyguanosine (8-oxoG) a specific oxidative DNA adduct in human cells, using the MutM protein (FAPY glycosylase, FPG).**

30        Detection of FAPY glycosylase (FPG) sites in specific-gene sequences. The QPCR gene-specific assay is a robust and sensitive assay for the detection of any type of DNA damage that leads to the inhibition of a thermostable DNA polymerase. While this assay efficiently detects most forms of base damage (thymine glycol) and DNA single and double strand breaks, some DNA  
35        lesions such as 8-oxodG are not effective blocks to DNA polymerases. To directly measure these adducts in

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specific gene sequences, it is necessary to first convert the 8-oxodG to a strand break with a glycosylase/endonuclease from *E. coli*, formamidopyrimidine DNA glycosylase (FPG) (MutM protein). Besides acting on 8-oxo-deoxyguanine adducts, this enzyme also removes ring-opened purines such as formamidopyrimidine (FAPY). Data displayed in FIG. 16 were generated using DNA from cells treated with acridine orange (AO) and light (L) for 3, 6, and 9 minutes. AO plus light generates single oxygen that causes a significant amount of 8-oxodG lesions. In this experiments the DNA was extracted and an aliquot was digested with FPG. The DNA was then used in a QPCR in which the 17.7 kb  $\beta$ -globin fragment was amplified. The relative amount of amplification was used to determine the lesion/17.7 kb. These results are very important for at least two important following reasons. This is the first time that 8-oxodG or ring-opened purines such as formamidopyrimidine have been detected in specific gene sequences from 15 nanograms of genomic DNA. Secondly, the amount of FPG sites preexisting in cellular DNA is 0.18 lesions/17.7kb which converts to 0.9 sites /100 kb. This is in good agreement of the number of 8-oxo-dG which can be detected in most cells grown in culture .

25

**EXAMPLE 10. Repair kinetics of cisplatin-DNA adduct in human cells.**

One of the major limitations of cancer chemotherapy is delivering an effective dose of the anti-cancer drug to the target tumor. One widely used anti-cancer drug, cisplatin (cis DDP), reacts with DNA to inhibit DNA replication and results in cell death. DNA adducts resulting from cisplatin treatment, are often rapidly repaired by tumor cells and can therefore be inactivated. The development of a rapid and efficient method for the quantitation of cisplatin-DNA adducts in patients

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undergoing cisplatin chemotherapy would allow more beneficial treatment strategies. Data in FIGs. 17A and 17B show the repair kinetics of transformed human fibroblasts which have been treated with cisplatin (150  $\mu$ M) for 2 hours and then allowed various time periods for repair ( $\beta$ -globin (FIG. 17A) and *hprt* (FIG. 17B)). The DNA was extracted and used for the long amplification. Note that cisplatin-DNA adducts are repaired slowly as compared to UV damaged DNA.

10

**EXAMPLE 11. Detection of benzo[a]pyrene diol epoxide-DNA adducts in human cells. DNA.**

15 Many environmental chemical pollutants can cause cancer in experimental animals. One such compound, benzo[a]pyrene diol epoxide (BPDE), is produced by combustion of fossil fuels and is found in cigarette smoke. BPDE is one of the most potent carcinogens known to man. Data in Figure 18A and 18B show the production of BPDE-DNA adducts in three different genomic regions in transformed human cells. Cells were treated with BPDE (none, 2  $\mu$ M and 4  $\mu$ M) and the DNA was used for quantitative amplification of long DNA fragments.

25

\* \* \* \* \*

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While the above description contains many specifics, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of preferred embodiments. Many other potential variations are possible, as would be apparent to one skilled in the art. Accordingly, the scope of the invention should be determined by the scope of the appended claims and their legal equivalents, and not just by the embodiments.

The following citations are incorporated in pertinent part by reference herein for the reasons cited in the above text.

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CLAIMS:

1. A method of assessing DNA damage in a test double-stranded DNA template comprising the steps of:

5

providing an amount of a control double-stranded DNA template with first and second complementary strands of DNA, the first and second complementary strands of DNA each having a strand-specific primer site, and the primer-sites being separated by at least about 5,000 base pairs;

10

combining the first and second complementary strands in a mixture with primers to the strand-specific primer-site on each of the complementary strands;

15

performing quantitative long DNA amplification on the mixture;

20

repeating the above steps with an amount of a test double-stranded DNA template subjected to DNA-damaging or potentially DNA-damaging conditions; and

25

assessing DNA damage by determining a lower amplification rate for test DNA as compared to control DNA.

30 2. The method of claim 1 wherein the double-stranded DNA template is a gene-specific double-stranded DNA template.

35 3. The method of claim 1 wherein the amount is from about 1ng to about 30ng.

- 40 -

4. The method of claim 1 wherein the amount is from about 5ng to about 15ng of DNA.

5 5. The method of claim 1 for determining a rate of DNA repair in a system, when further comprising the steps of:

10 removing test double-stranded DNA template samples from the biological system at at least two different times after subjection to DNA-damaging conditions;

assessing DNA damage in each sample; and

15 determining DNA repair rate by measuring increases in DNA amplification rates.

20 6. The method of claim 1 for diagnosing efficacy of an anti-neoplasia therapy in a patient comprising the steps of:

25 obtaining samples of a double-stranded DNA template from a patient prior to therapy and at least at one subsequent time;

processing each sample separately using the method of claim 1; and

30 assessing DNA damage in each sample by decreases in amplification rate;

wherein therapeutic efficacy is proportional to DNA damage

35

- 41 -

7. A method of evidencing the presence of environmental genotoxicity comprising the steps of:

5 obtaining a control double-stranded DNA template sample, and at least one double-stranded DNA template environmental sample;

10 subjecting each sample to DNA amplification where primer sites are separated by at least about 5,000 base pairs; and

comparing DNA amplification rates in the control sample with environmental samples;

15 wherein environmental genotoxicity is inversely proportional to any decrease in DNA amplification rate of environmental samples.

20 8. A method of assessing genotoxic agents in an environmental sample, comprising the steps of:

25 obtaining a sample of double-stranded DNA and an environmental sample suspected of comprising a genotoxin;

subjecting a test portion of the DNA sample to intimate contact with the environmental sample for a period of time;

30 subjecting the sample and test portion to DNA amplification with primers for DNA sites separated by at least about 5,000 base pairs; and

35 comparing DNA amplification of the control with that of the test DNA;

- 42 -

wherein amounts of genotoxins are assessed by decreases in DNA amplification with test samples.

- 5     9.    The method of claim 8 where mapping of an environmental genotoxin hazard site is accomplished by:

          subjecting DNA samples to environmental samples from  
          different map locations; and

10

          placing assessed amounts of genotoxin agents on map  
          locations to form a genotoxin hazard map of  
          said environment.

15

10.   A personal DNA genotoxin exposure dosimeter  
      comprising:

20

          at least two double-stranded DNA template samples,  
          having DNA primer sites separated by at least  
          5,000 base pairs, at least one sample being  
          exposable to the environment and one sample  
          being a control sealed from environmental  
          exposure; and

25

          a means for attaching said dosimeter to a person.

- 30   11.   A method of monitoring an individual's exposure to genotoxins over an interval of time comprising the steps of:

          attaching the dosimeter of claim 11 to an  
          individual;

35

          exposing at least one sample to the environment;

- 43 -

subjecting the DNA samples to amplification with  
primers for the primer sites; and

5            assessing genotoxin exposure by determining any  
             decrease in amplification rate resulting from  
             environmental exposure.

12. A method of detecting DNA damage resulting in 8-oxo-  
10       deoxyguanosine or formamidopyrimidine, the method  
         comprising:

         obtaining a first double-stranded DNA template with  
             first and second complementary DNA strands, the  
15           first and second complementary strands each  
             having a strand-specific primer site and the  
             primer sites being separated by at least about  
             5,000 base pairs;

20           reacting a portion of the first double-stranded DNA  
             template with glycosylase/endonuclease or  
             formamidopyrimidine DNA glycosylase to convert  
             DNA damage into a strand break, resulting in a  
             second double-stranded DNA template sample;

25           combining the first and second complementary strands  
             of the first sample and the second sample  
             separately with primers to the strand-specific  
             primer sites on each of the complementary  
30           strands;

         performing long DNA amplification on the control  
             sample and the test sample;

35           assessing DNA damage due to formation of 8-oxo-  
             deoxyguanosine or formamidopyrimidine by observing

- 44 -

decreases in the rate of DNA amplification of the second sample as compared to the first sample.

- 5    13. A method of assessing DNA damage induced by cis-platin, the method comprising:

10                    obtaining a first DNA template sample from a patient  
                     subject to cis-platin therapy, the sample  
                     comprising double-stranded DNA template with a  
                     first and second complementary DNA strand, the  
                     first and second complementary strands each  
                     having a strand-specific primer site and the  
                     primer sites being separated by at least 5,000  
15                    base pairs;

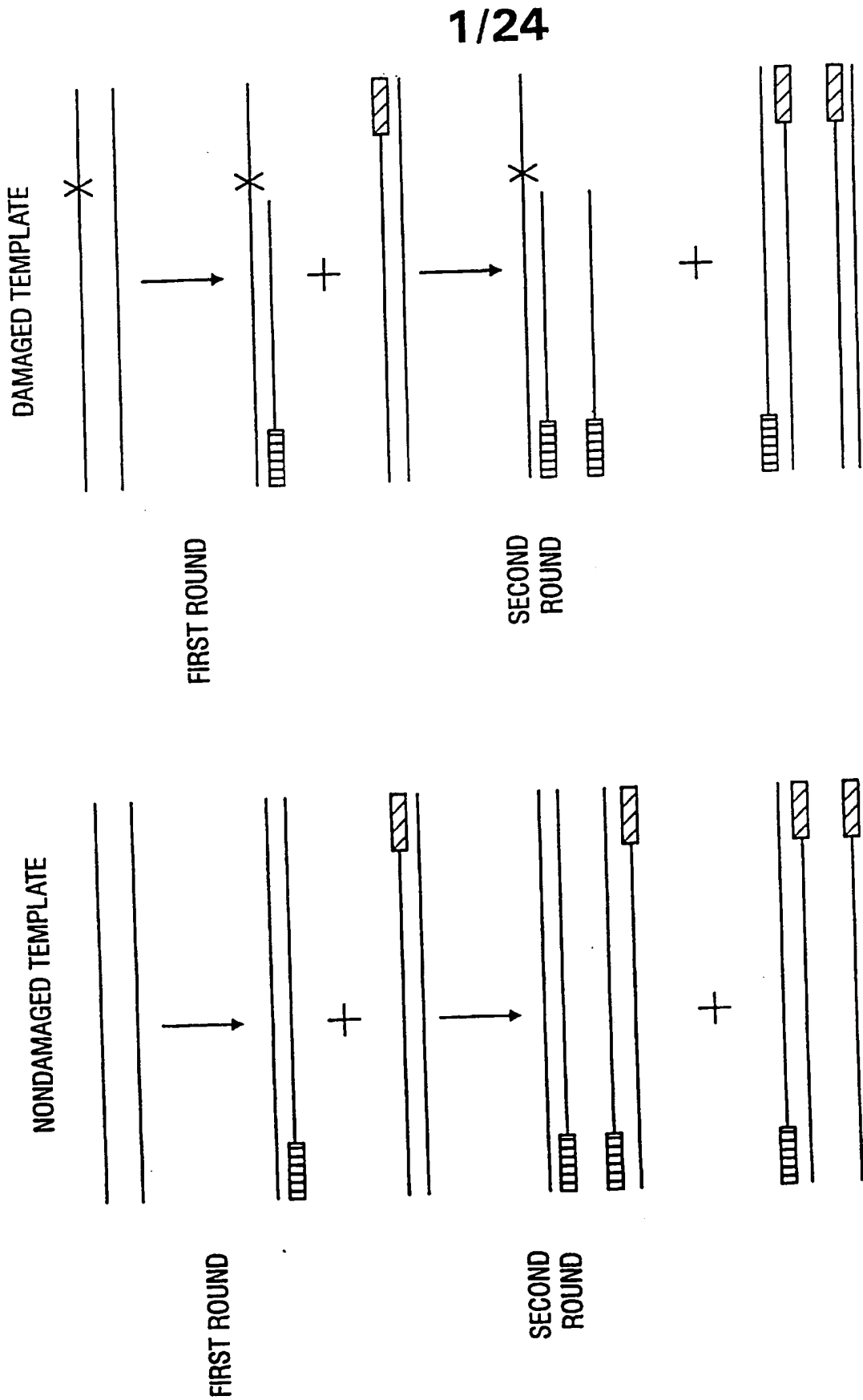
                     reacting a portion of the first DNA template with an  
                     amount of cyanide ion displacing cis-platin  
                     adducts from the DNA to form a second DNA  
20                    template;

                     separately combining the first and second  
                     complementary DNA strands from the first and  
                     second DNA templates with primers to the  
25                    strand-specific primer site on each of the  
                     complementary strands;

                     performing quantitative long-DNA amplification on  
                     the first and the second DNA templates;

30                    wherein the second template is a control and decreased  
                     rate of amplification of the first DNA template as  
                     compared to the control DNA is a measure of cis-platin-  
                     induced DNA damage.

35





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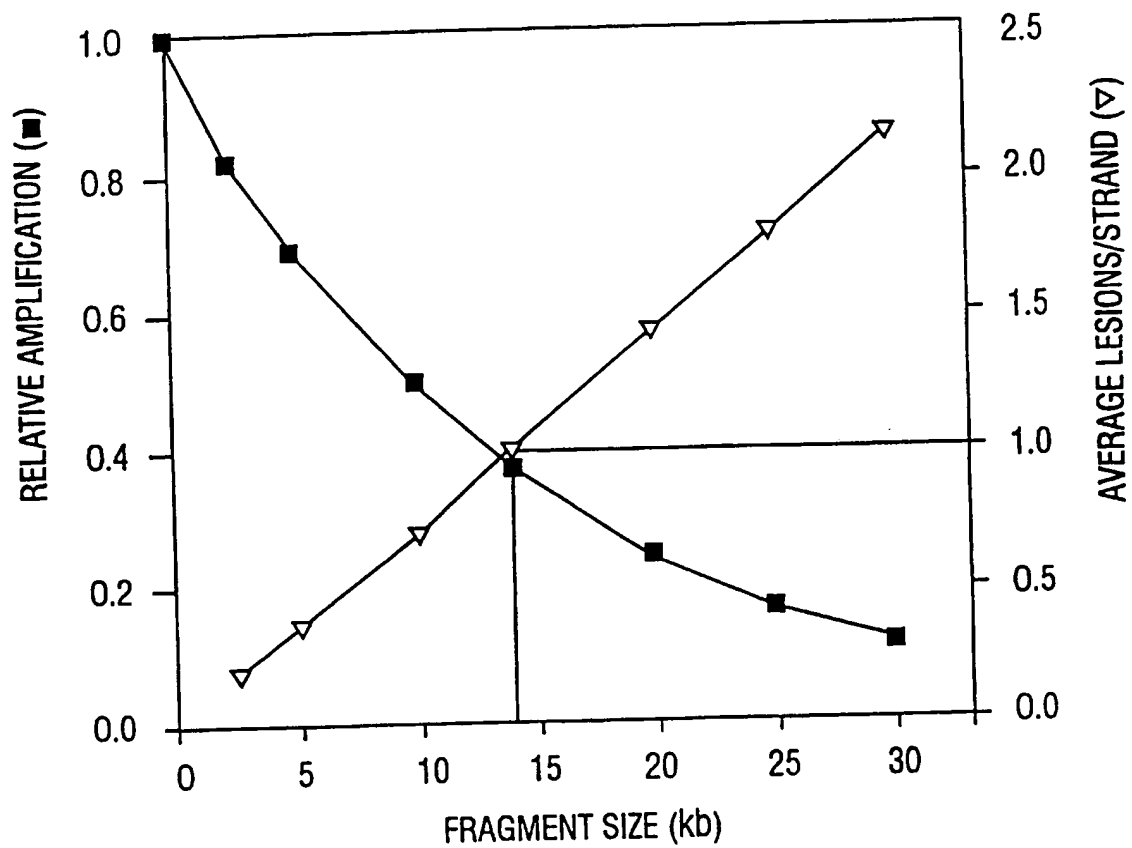


FIG. 1B

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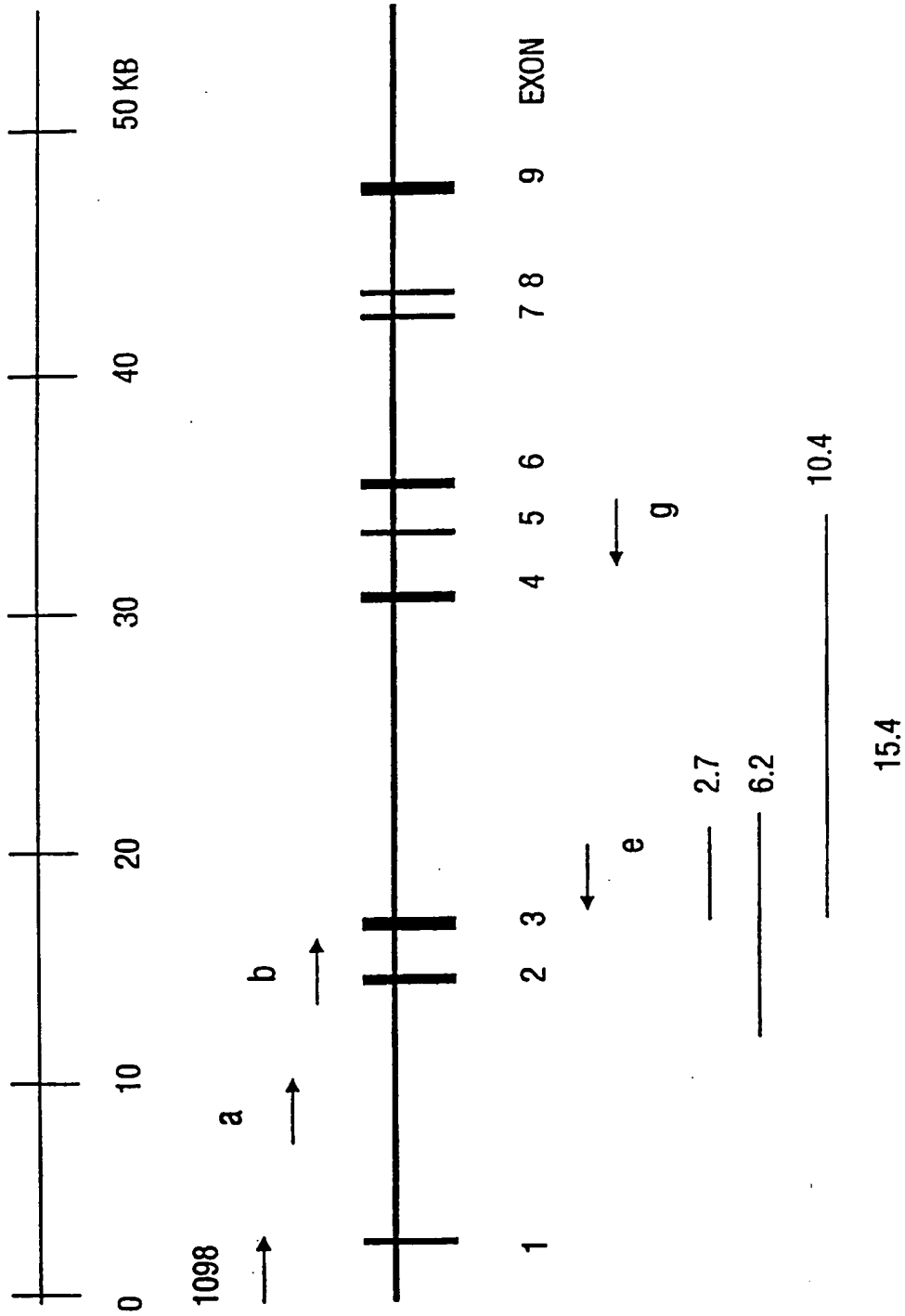


FIG. 2

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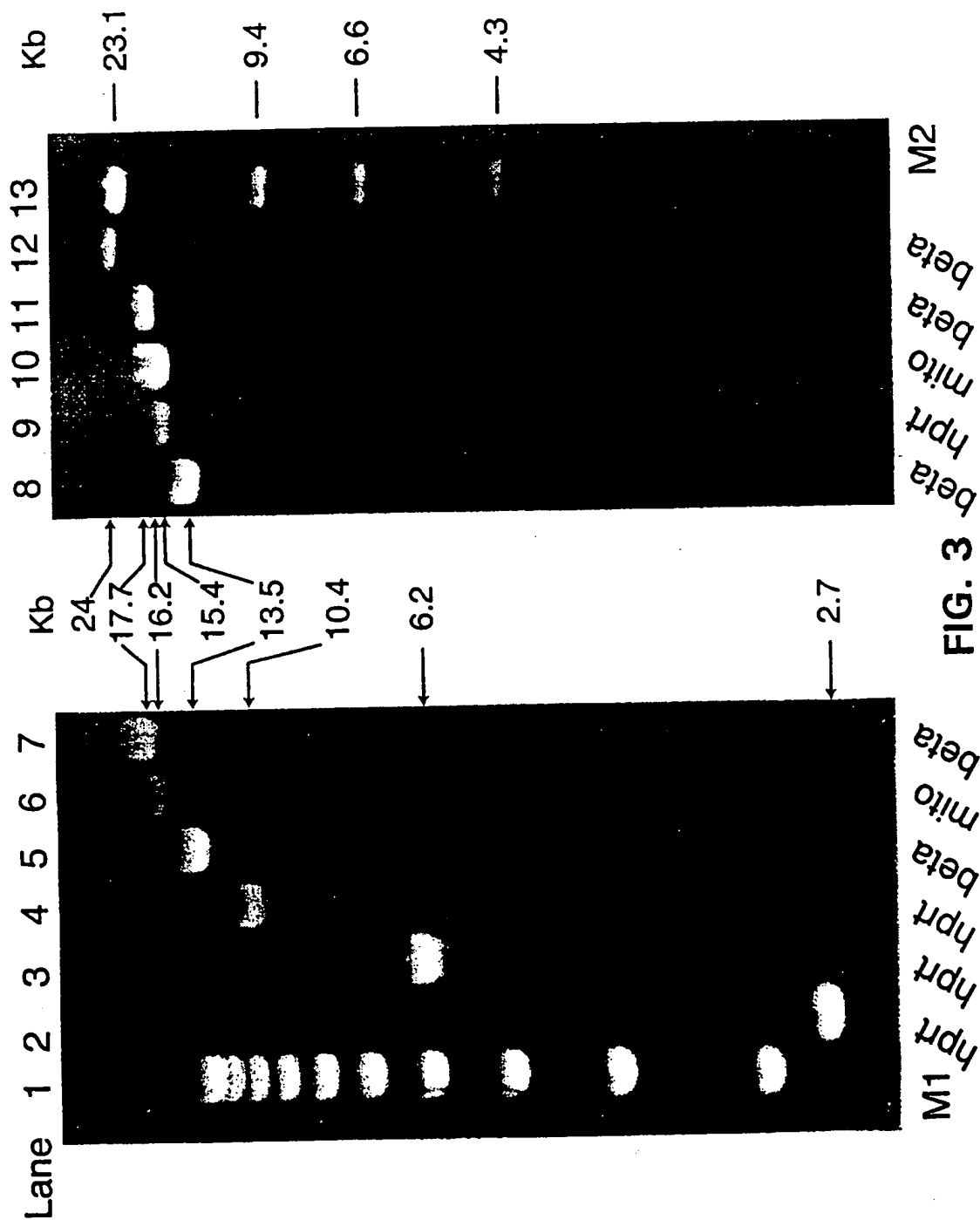


FIG. 3

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Fragment size	Rel. Amp	Lesions/Fragment	Lesions/kb
2.7 kb	$0.69 \pm 0.015$	$0.38 \pm 0.013$	$0.139 \pm 0.008$
6.25 kb	0.40	0.92	0.147
13.5 kb	0.125	2.09	0.154
15.4 kb	$0.15 \pm 0.005$	$1.98 \pm 0.023$	$0.123 \pm 0.002$
17.7 kb	$0.08 \pm 0.01$	$2.51 \pm 0.10$	$0.142 \pm 0.009$
24 kb	0.11	2.20	0.09

FIG. 4

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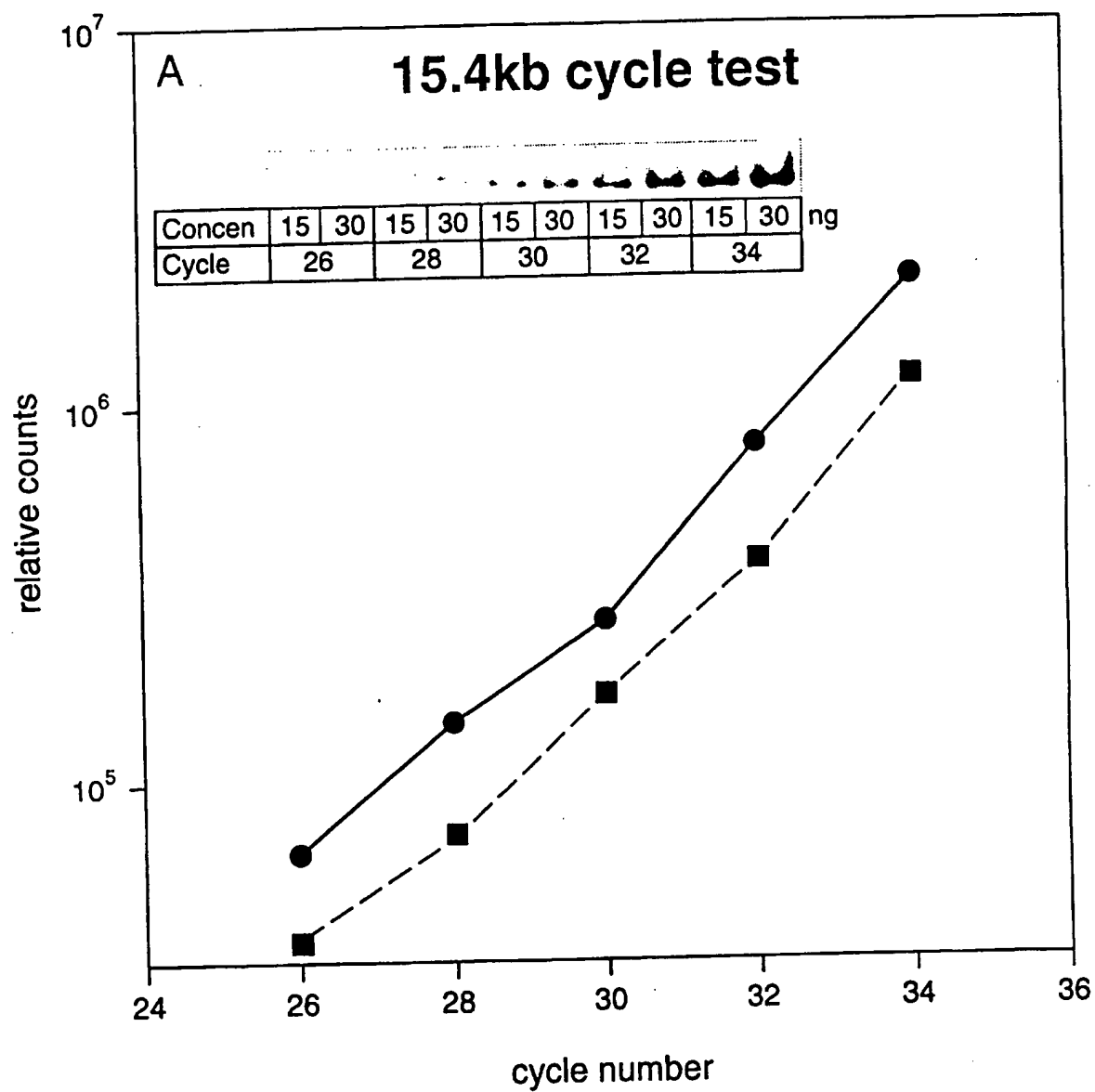


FIG. 5A

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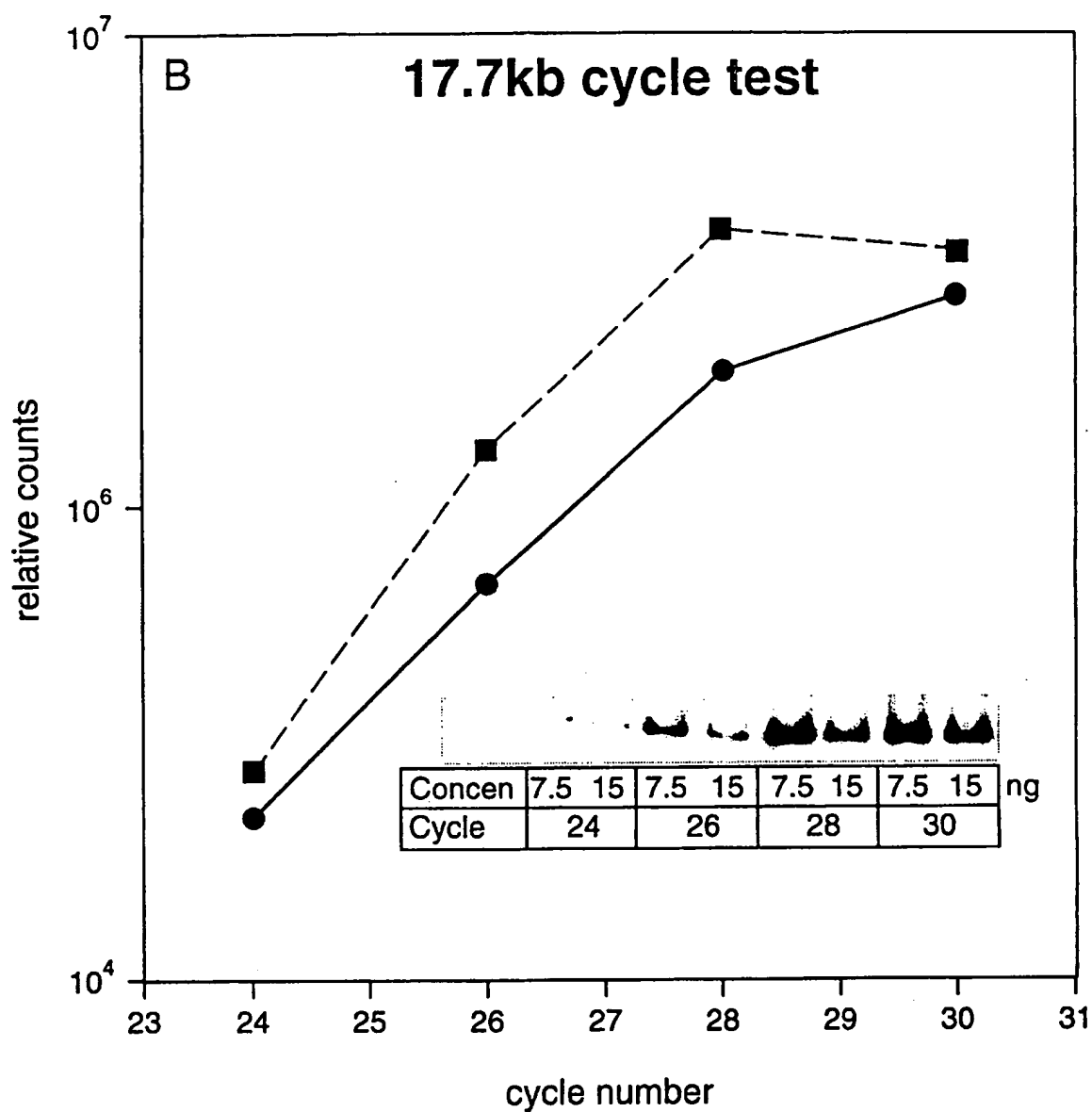


FIG. 5B

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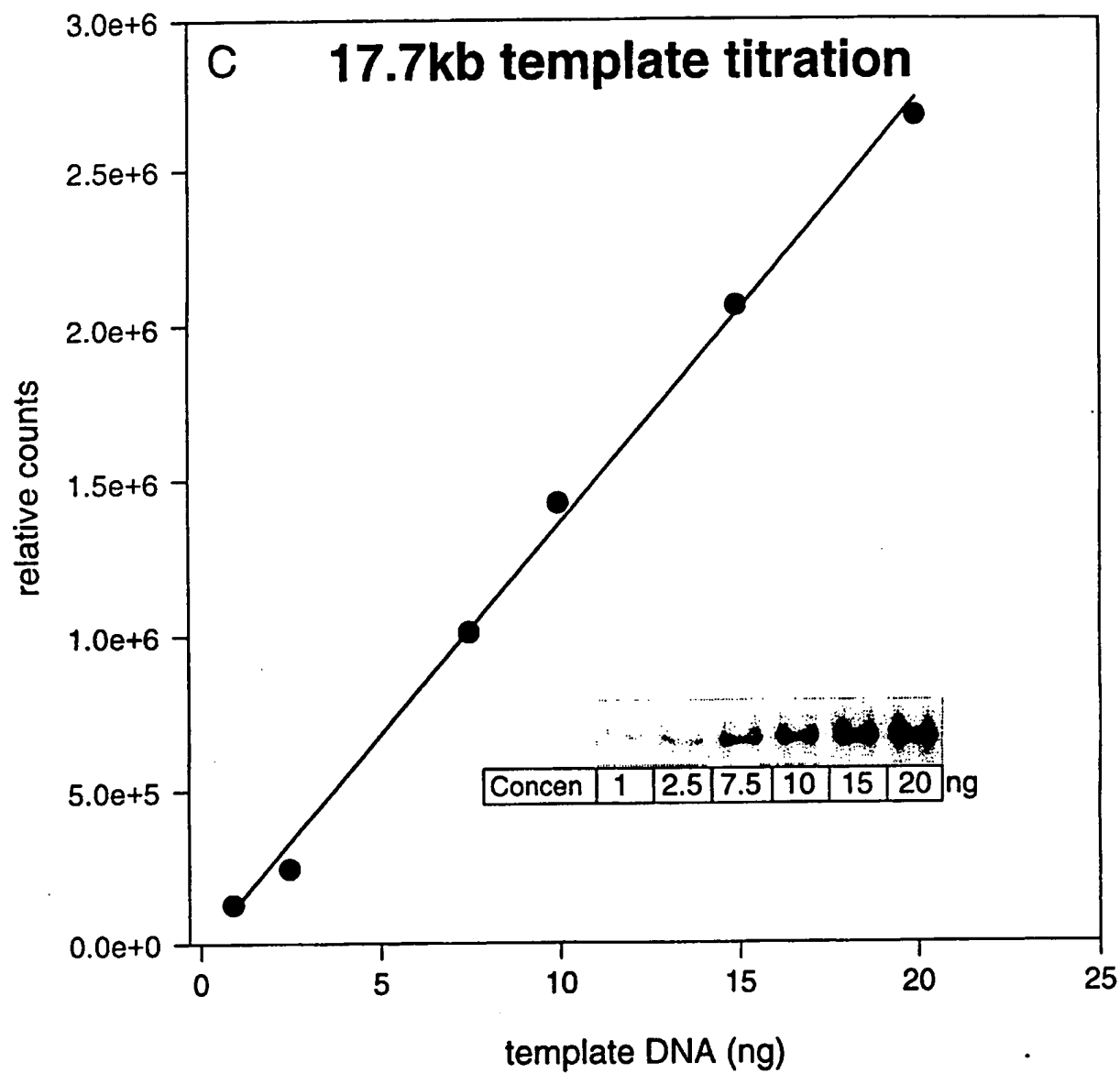


FIG. 5C

SUBSTITUTE SHEET (RULE 26)

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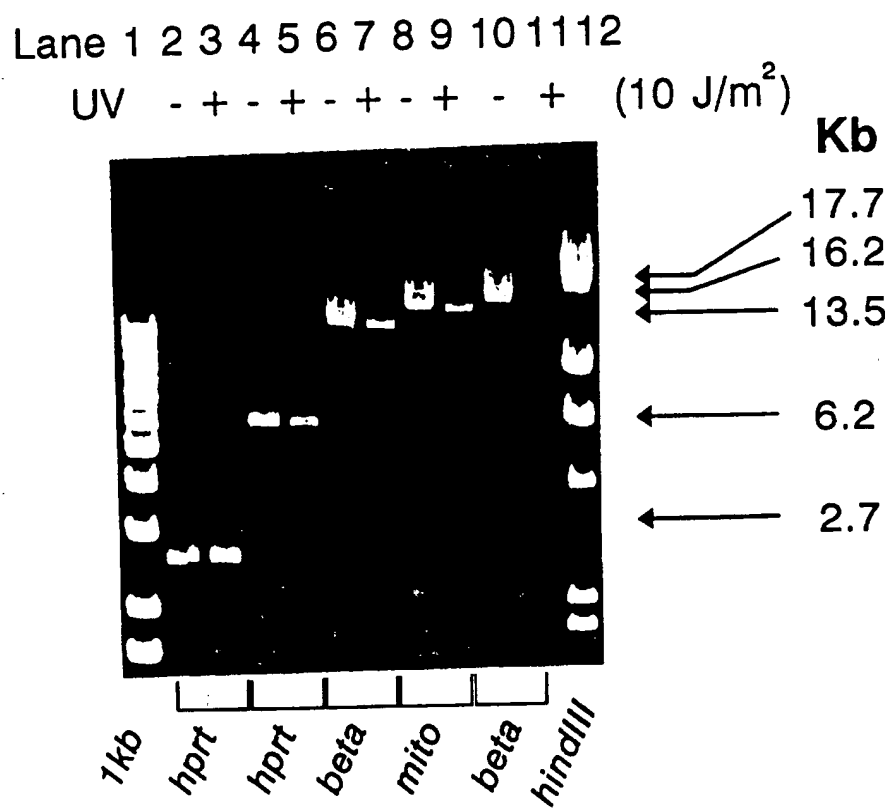


FIG. 6



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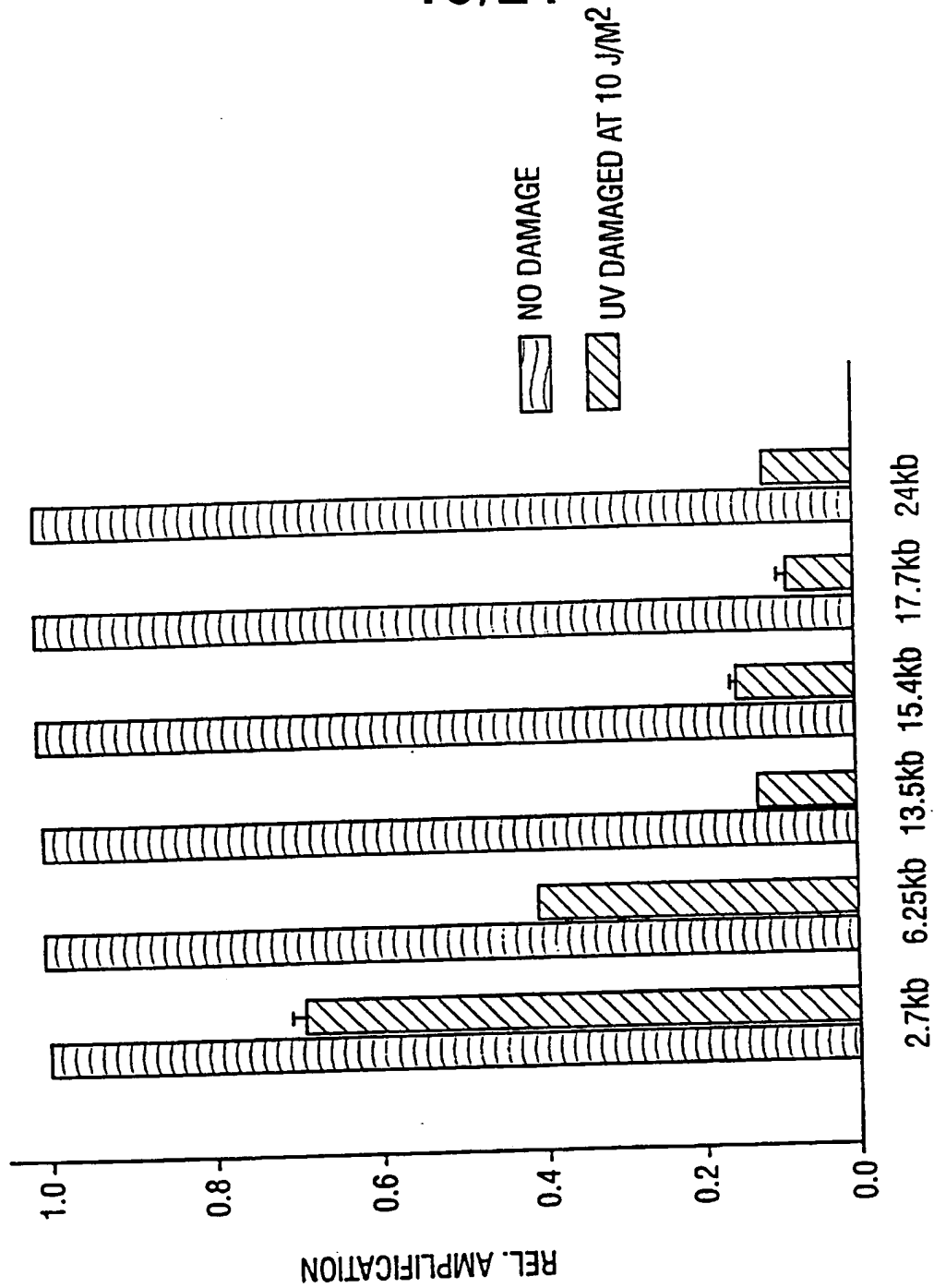


FIG. 7

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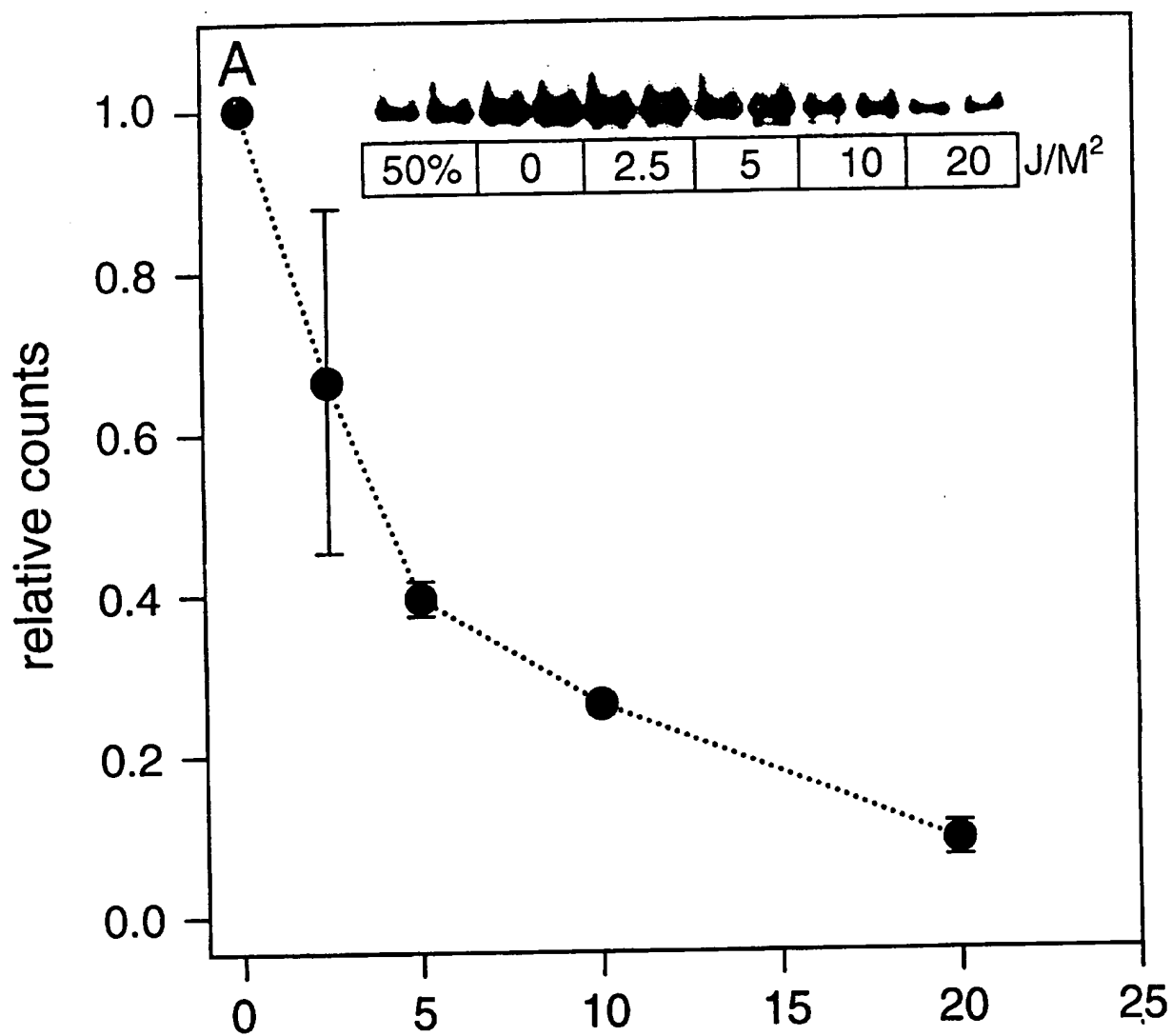


FIG. 8A

SUBSTITUTE SHEET (RULE 26)

12/24

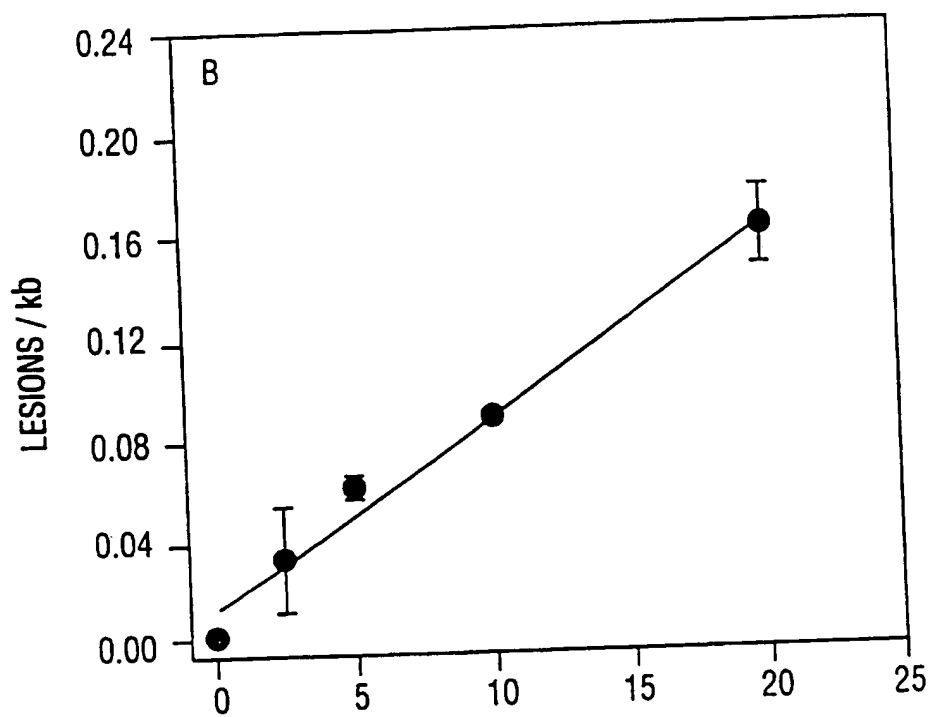


FIG. 8B

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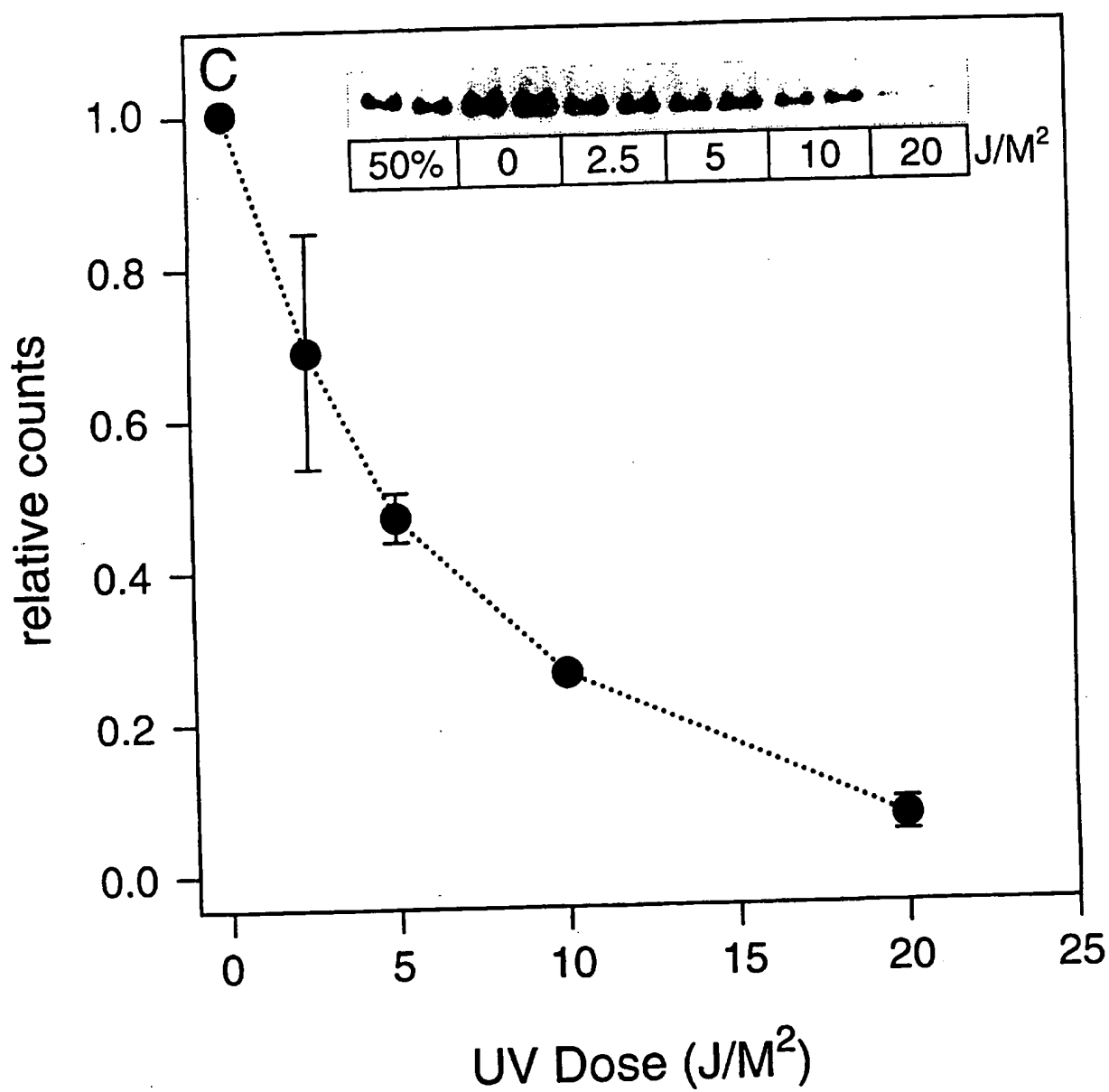


FIG. 8C

SUBSTITUTE SHEET (RULE 26)

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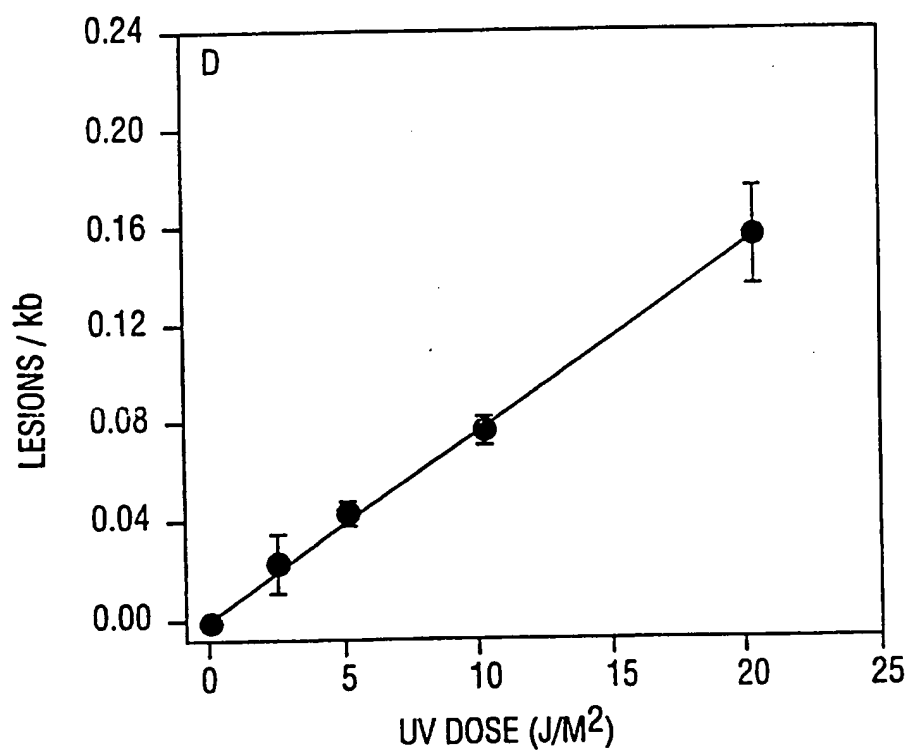


FIG. 8D

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Fragment size	UV Dose ( $\text{J/M}^2$ )									
	0		25		5		10		20	
	Rel. Amp	Lesion/kb	Rel.Amp	Lesions/kb	Rel.Amp	Lesions/kb	Rel.Amp	Lesions/kb	Rel.Amp	Lesions/kb
625kb	1.00	0	$0.65 \pm 0.12$	$0.072 \pm 0.029$	$0.70 \pm 0.16$	$0.058 \pm 0.035$	$0.56 \pm 0.13$	$0.095 \pm 0.039$	$0.28 \pm 0.08$	$0.21 \pm 0.05$
154kb	1.00	0	$0.61 \pm 0.24$	$0.035 \pm 0.023$	$0.40 \pm 0.02$	$0.039 \pm 0.004$	$0.27 \pm 0.02$	$0.085 \pm 0.004$	$0.08 \pm 0.02$	$0.16 \pm 0.017$
17.7kb	1.00	0	$0.692 \pm 0.27$	$0.024 \pm 0.021$	$0.47 \pm 0.06$	$0.045 \pm 0.0066$	$0.26 \pm 0.05$	$0.079 \pm 0.010$	$0.073 \pm 0.05$	$0.16 \pm 0.04$

FIG. 9

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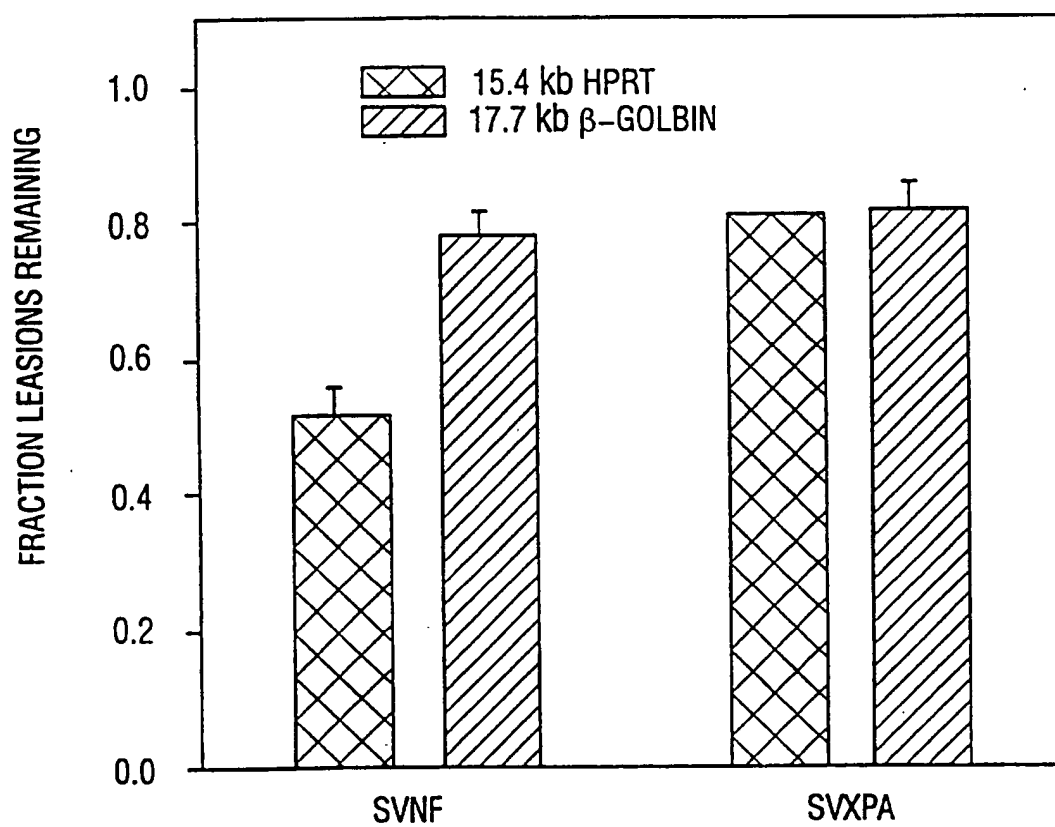


FIG. 10

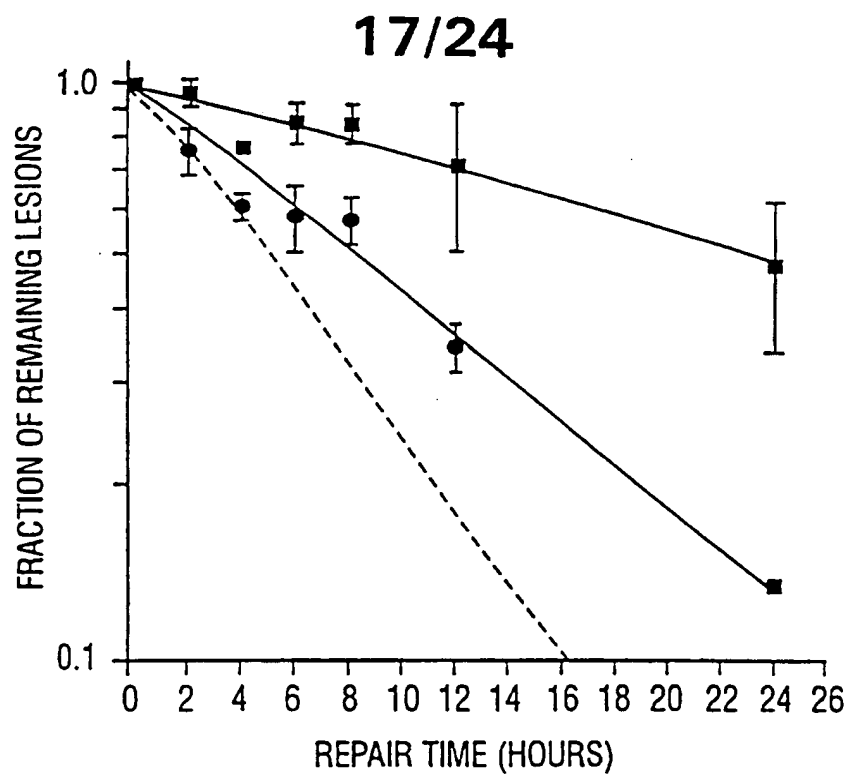


FIG. 11A

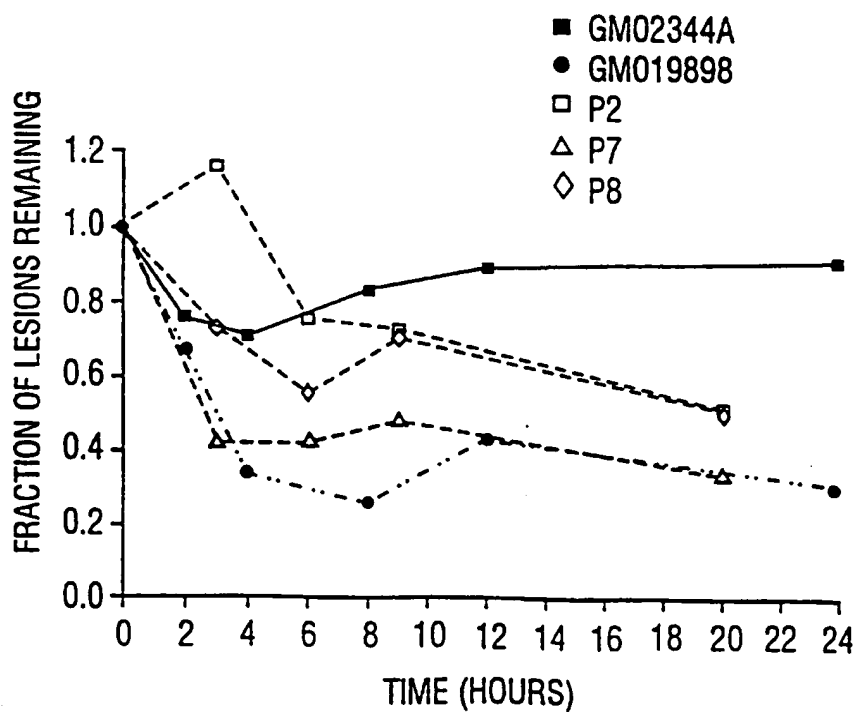


FIG. 11B

SUBSTITUTE SHEET (RULE 26)



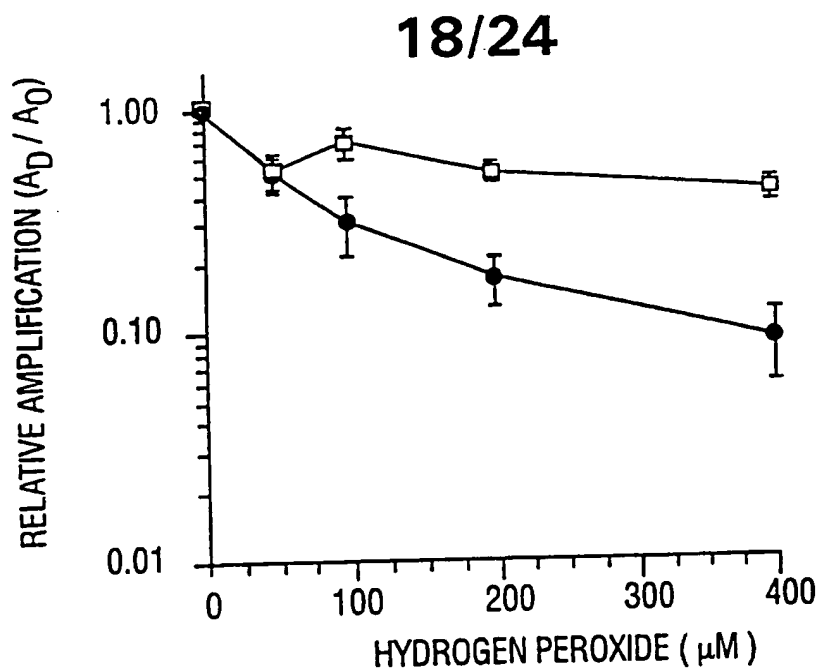


FIG. 12A

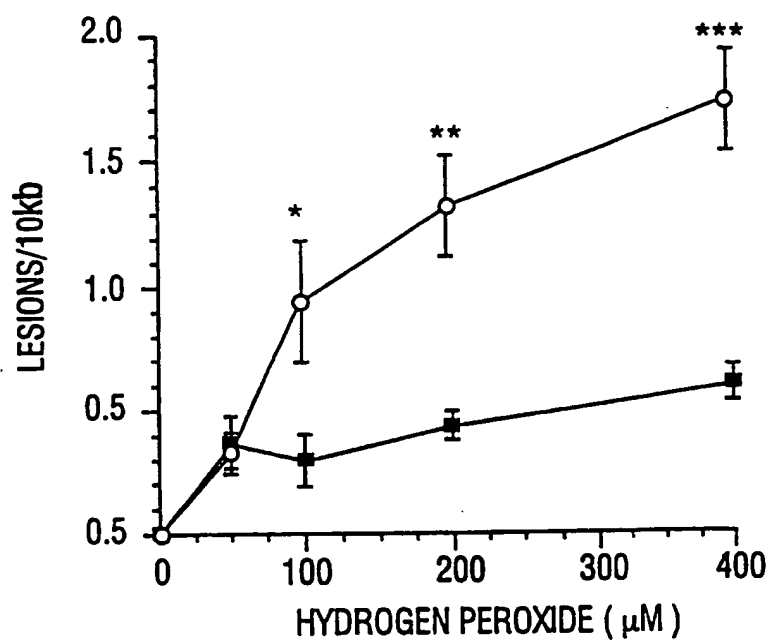


FIG. 12B

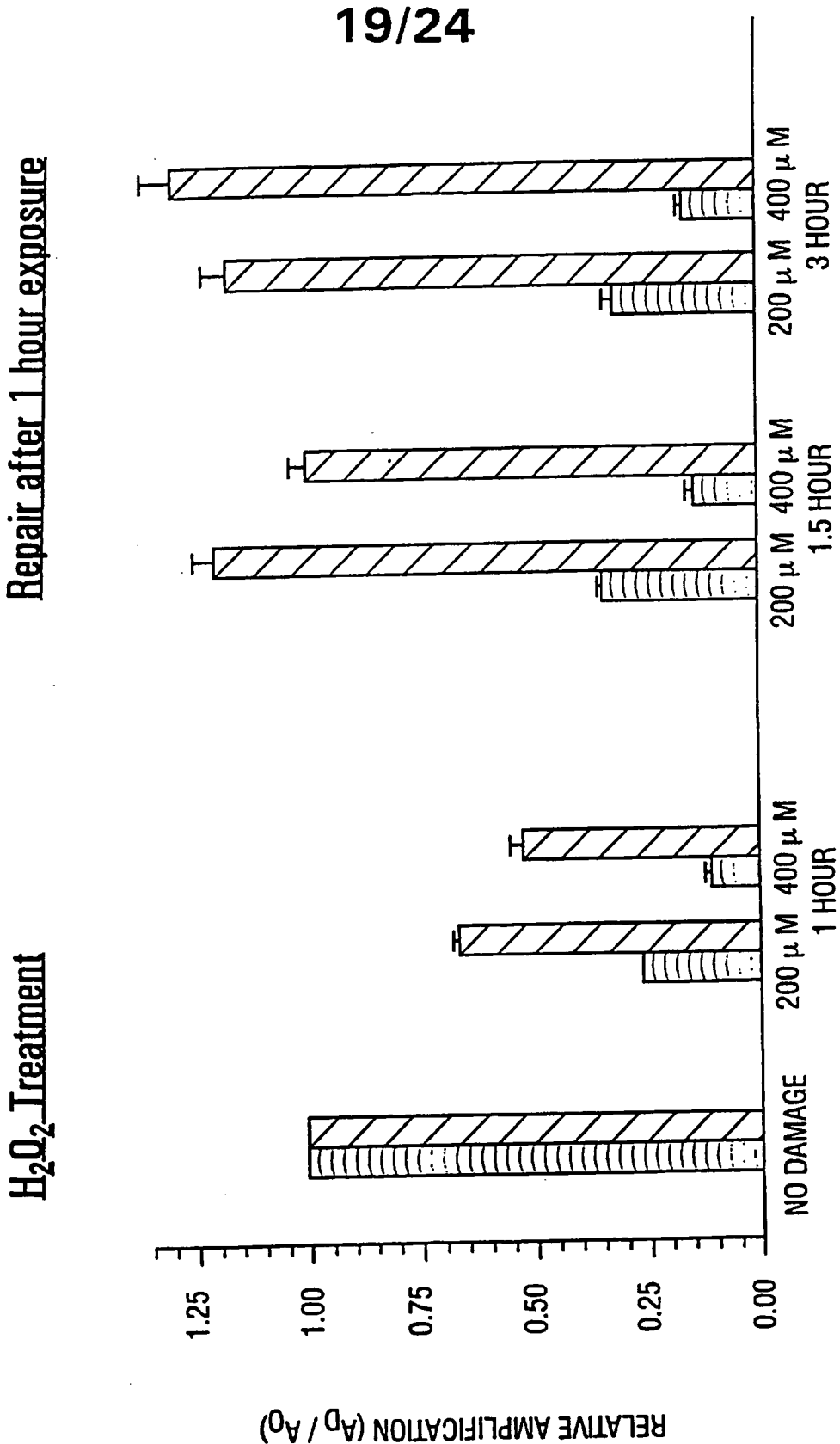


FIG. 13

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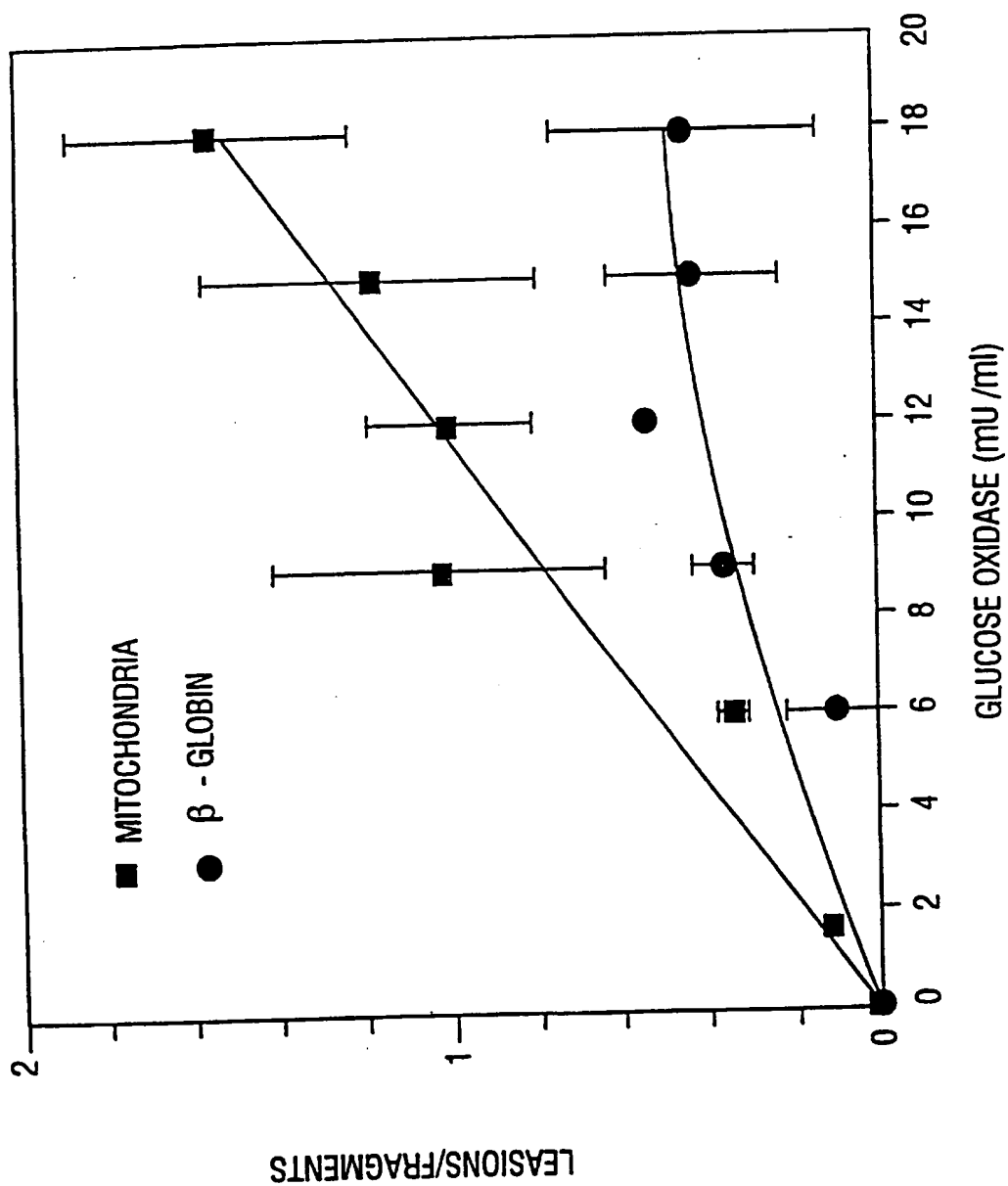
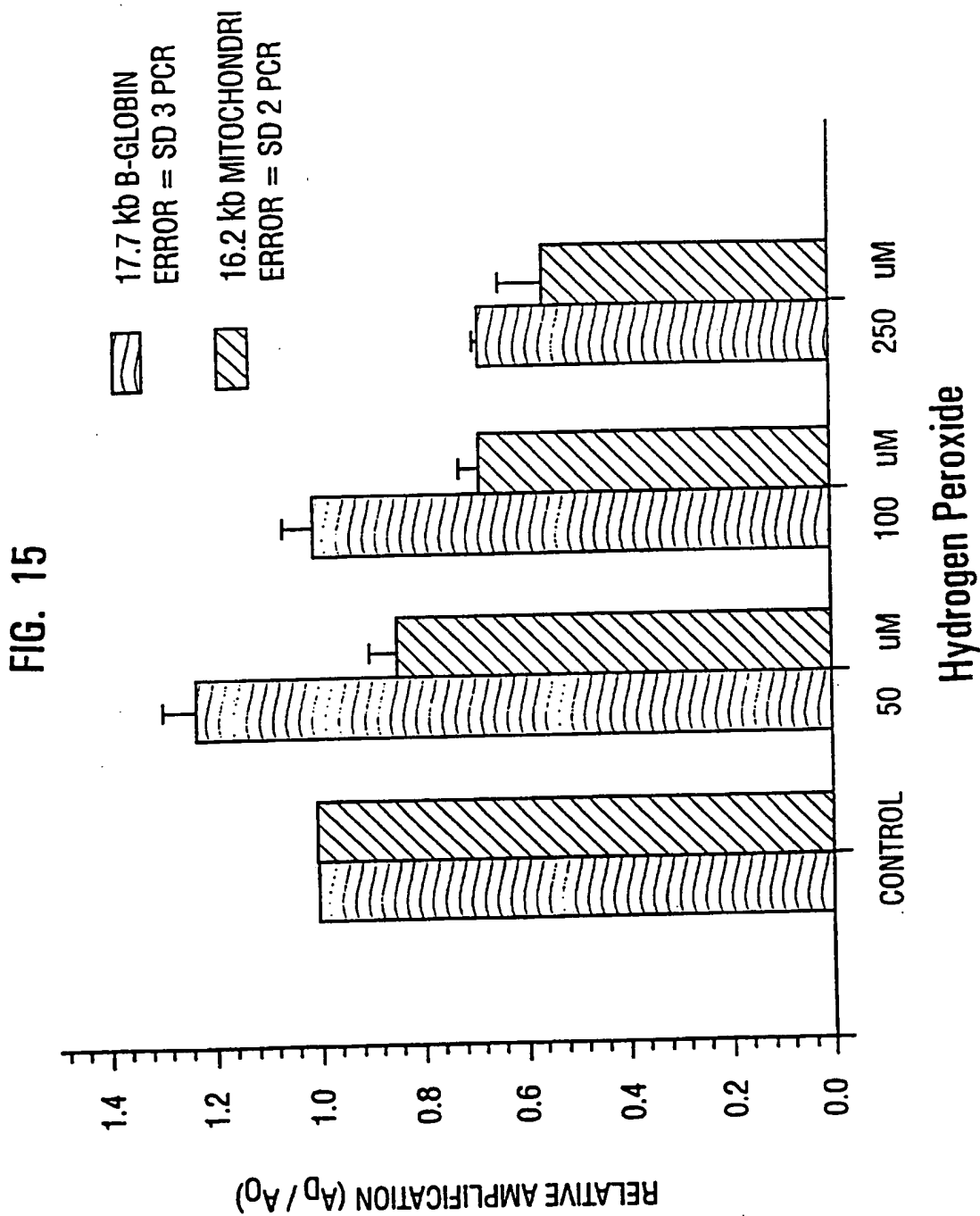


FIG. 14

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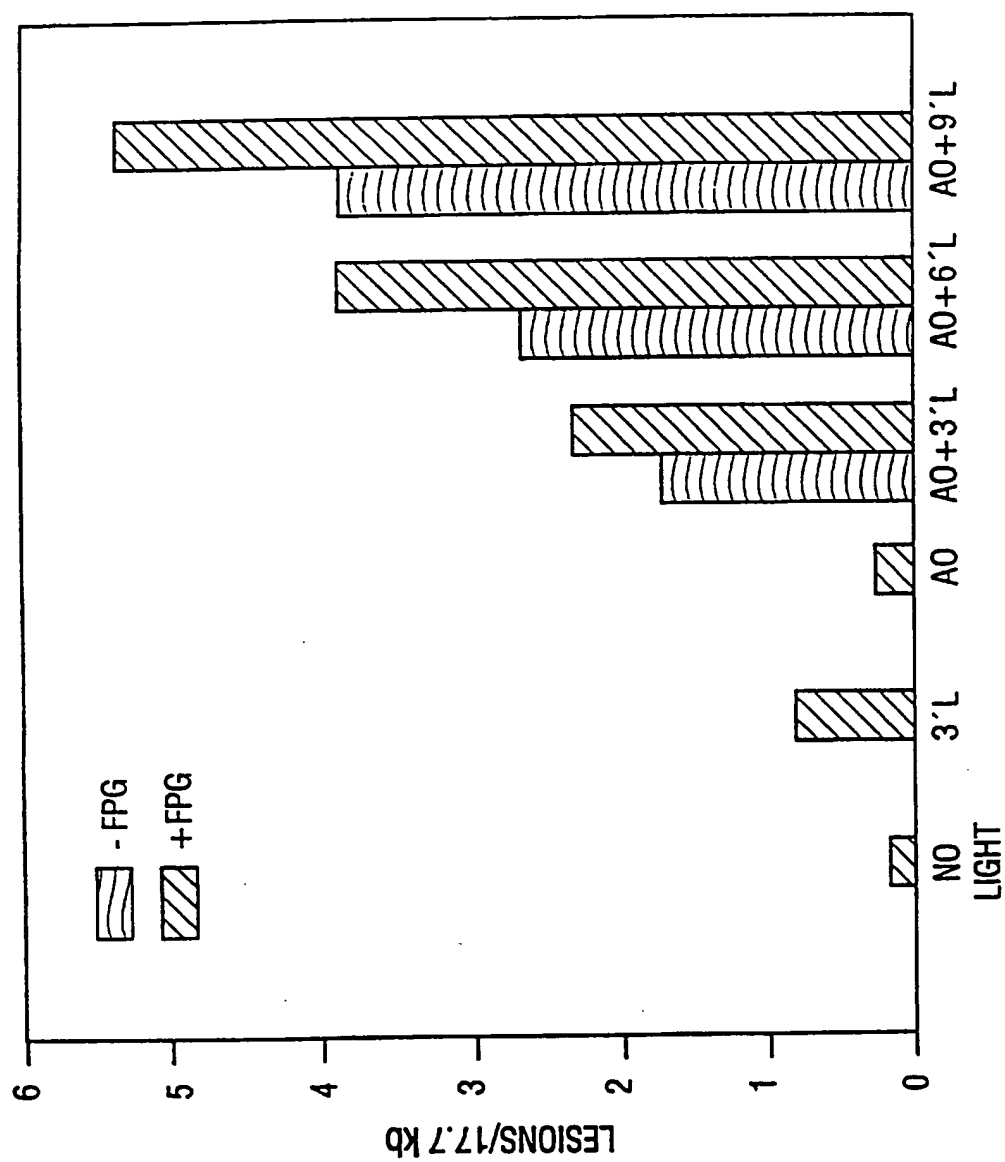


FIG. 16

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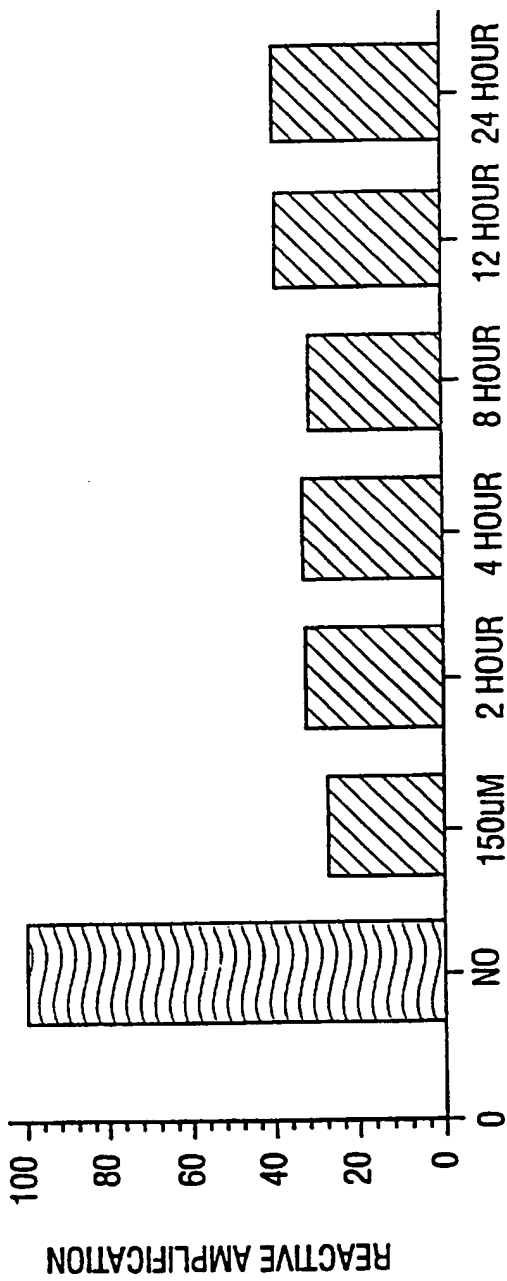


FIG. 17A

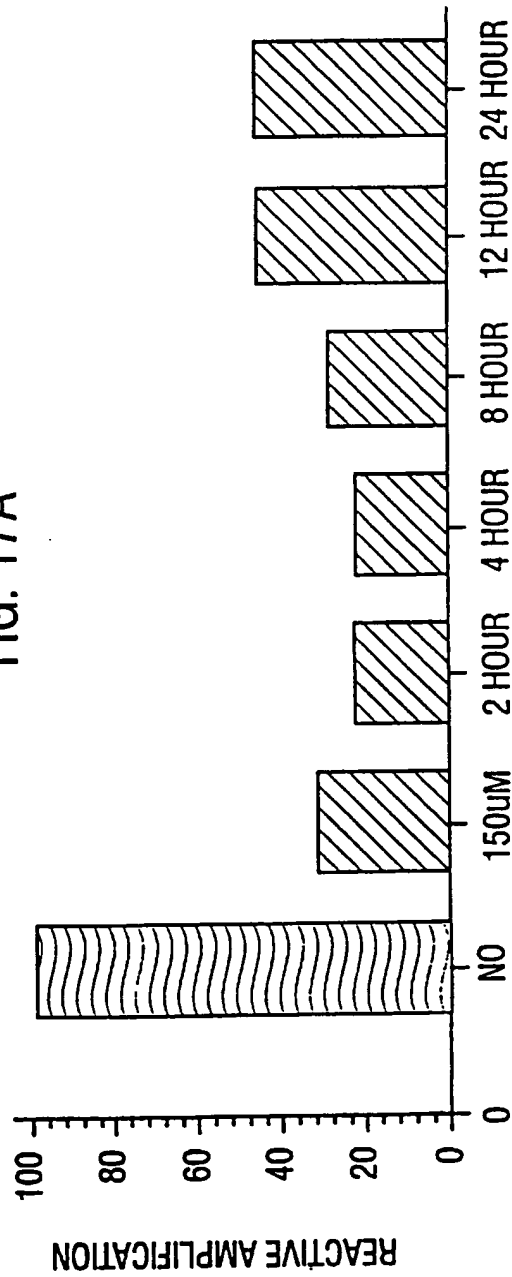


FIG. 17B

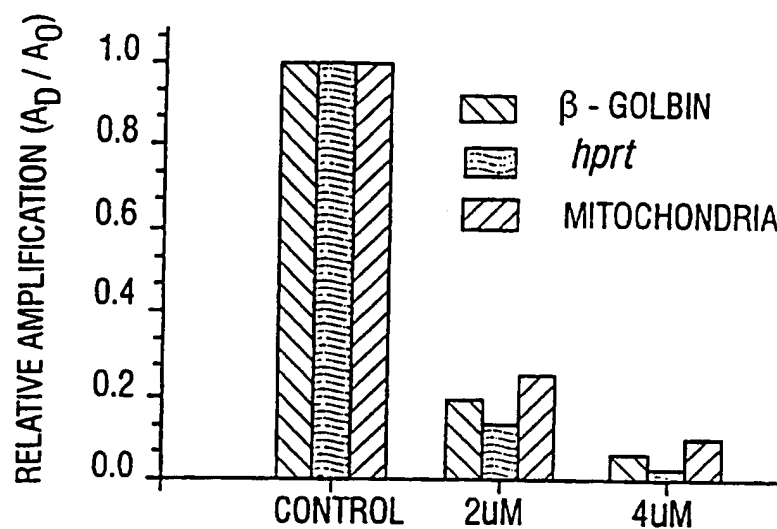
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FIG. 18A

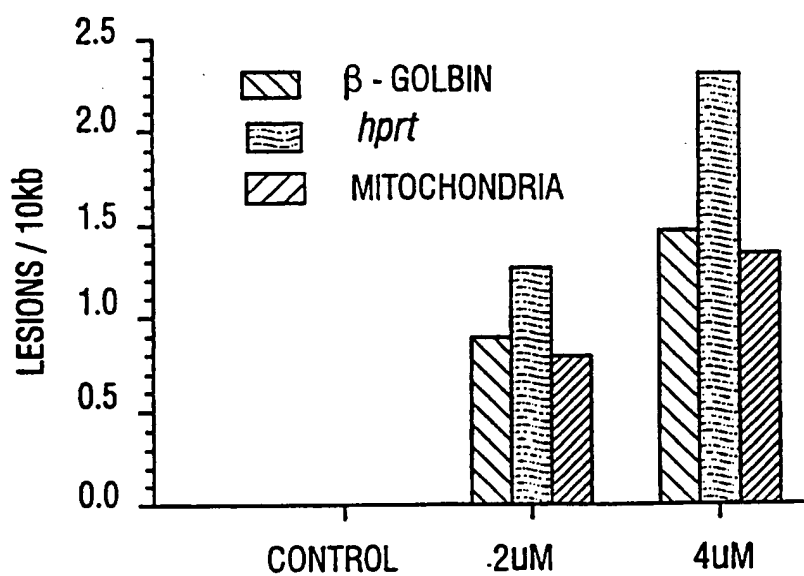


FIG. 18B

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/01127

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C12P 19/34  
US CL : 435/91.2  
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
U.S. : 435/91.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
USPAT, MEDLINE, BIOSIS, CA  
search terms: quantitative pcr, damage, lesion, repair, genotoxin, mapping

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	KALINOWSKI et al. Analysis of DNA Damage and Repair in Murine Leukemia L1210 Cells Using a Quantitative Polymerase Chain Reaction Assay. Nucleic Acids Research. 1992, Vol. 20, No. 13, pages 3485-3494, especially page 3486.	1, 2 and 5-12 ----- 3, 4, 13
Y	MORRIS et al. A YAC Contig Spanning the Nevroid Basal Cell Carcinoma Syndrome, Fanconi Anaemia Group C, and Xeroderma Pigmentosum Group A Loci on Chromosome 9q. Genomics. 1994, Vol. 23, pages 23-29, especially, page 24.	3
Y	DENISSENKO et al. Assessment of DNA Damage and Repair in Specific Genomic Regions by Quantitative Immuno-coupled PCR. Nucleic Acids Research. 1994, Vol. 22, No. 12, pages 2351-2359, especially page 2353.	4

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*E* earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*G*	document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means		
*P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  
17 MAY 1996

Date of mailing of the international search report  
10 JUN 1996

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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/01127

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JENNERWEIN et al. A Polymerase Chain Reaction-Based Method to Detect Cisplatin Adducts in Specific Genes. Nucleic Acids Research. 1991, Vol. 19, No. 22, pages 6209-6214, especially page 6210.	13